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RUSSIAN STEAM LOCOMOTIVES IN THE LAST 50 YEARS

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This book contains a historical review of the development of steam locomotive building in our country from the end of the last century to modern times. The book is divided into four chapters. The first chapter is devoted to the activities of the founders and leaders of locomotive building and the remaining three deal with the history of the development of different types and designs of steam locomotives - freight, passenger, and those without tenders (tanks, switchers, and train locomotives).

The book was written for workers concerned with the problems of locomotive building, as well as for readers who are interested in the history of science and technology in our country.

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FOREWORD

The history of steam locomotive building in our country can be divided into three periods: the first -- from the day of building the first Russian locomotive to the end of the XIX century, the second -- from the end of the XIX century to the Great October Socialist Revolution, and the third -- since the Great October Socialist Revolution.

The first steam locomotive in Russia was built by Ye. A and M. Ye. Cherepanov in 1833. In the period between this important date and the end of the XIX century, Russian locomotive [illegible] a lot for the development of the domestic locomotive-building. During this period many types of locomotives (1-2-0, [illegible], and [illegible]), called subsequently series D, T, and Ch, were designed and built. These types of locomotives became obsolete a long time ago and they were taken out of service, but still they represented the foundation of Russian locomotive building.

By 1917, locomotive building in Russia was extensively developed and became one of the foremost branches of industry. Many types of Russian locomotives were built, for the designation of which series the whole alphabet was utilized.

Many types of locomotives were much better in quality than similar types of locomotives of foreign design. For instance, in spite of the fact that at that time foreign locomotive building employed carbon steels, still the Russian locomotive of the B. S. [illegible] 1-3-1 series and of the A.S. Rayevskiy 2-3-1 L series in capacity per unit of weight had the highest rating in the world.

[illegible] October Socialist Revolution scientific [illegible] activity in the field of design advanced at [illegible] rate [illegible] in history. As a result, there were created in the [illegible] types of locomotives in the world, the IS, FD, L, [illegible] and others.

[illegible] important stages in the development of Russian [illegible] place during the last 50 years, i.e. in [illegible] periods of the development of locomotive [illegible]. Precisely this induced the author to devote his work [illegible] to these two periods.

The author confined himself to the history of steam loco- [illegible] gauge with steam pressure of 11 to 17 [illegible].

In the process of compiling this work, published and offic- [illegible] were used as well as personal recollections of leading [illegible] in the [illegible] locomotive building industry which were [illegible] personal conversations.

[illegible] did not permit the author to deal with certain [illegible] desired. All comments and any supplemen- [illegible] send to the author will be accepted by the [illegible].

[illegible] his deep gratitude to the [illegible] Plant L. S. Lebedyanskiy, Professor [illegible], Docent [illegible] Pavlov, Candidate of Technical Sciences

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[illegible] and [illegible] Khile[illegible], Ye. A. Shiryayev, [illegible] and others, who contributed valuable information and [illegible] which were utilized in the present work.

The Author.

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I. THE DEVELOPMENT OF STEAM LOCOMOTIVE BUILDING IN OUR COUNTRY

1. GENERAL REVIEW

Steam locomotive building in our country came into being over one hundred years ago. It contained the collective thought of many generations of distinguished theoreticians and practical men, whose creative activity brought this branch of technical art to a high degree of modern development.

In 1762 a Russian inventor I. I. Polzunov built in Barnaul a coupled steam engine which was the first in the world. Polzunov's name remained unknown for a long time, because the Tsarist Government did not encourage Russian inventors.

Polzunov with his invention of the steam engine was over twenty years ahead of Watt. The date of Watt's building his steam engine is considered by bourgeois historians as the official beginning of steam technology.

The principle of the conversion of thermal energy into mechanical, which was the basis for the industrial revolution, was first utilized in Russia.

The use of the engine invented by Polzunov as a means of transport led to the invention of the locomotive, which started a new era of land transport on rails.

For us who live at the time when the globe is covered with the steel web of railroads, it is difficult even to imagine the ways in which mankind lived before the appearance of railroads. The analysis of figures indicates that on the average railroads increased the speed of land transport five times, brought the cost of it down six times, and increased its safety eight times, to say nothing of incomparably greater regularity in dates of delivery. (Transactions of the Scientific Technical Committee of the People's Commissariat of Communications, issue No. 20, Moscow, 1926, page 126.)

The first pioneer of rail transport in Russia was P. K. Frolov, who built the first Russian railroad for the Zmeinogorsk mines in 1806, i.e., 13 years ahead of the first railroad in France and 17 years before the building of the first railroad in America.

The first locomotive in Russia was built by two serfs, mechanics by trade, the two talented self-made men, father and son Ye. A. and M. Ye. Cherepanov, in 1833 at the Nizhniy Tagil Plants in the Urals, two years before the first locomotive was built in Germany.

These talented innovators did not find any support from the ruling circles of Tsarist Russia. This is explained by the lack of faith on the part of the latter in Russian technical ideas, as well as by their obscurantism, ignorance, and servile adulation of anything foreign. For this reason locomotives for the first Russian railroad between St. Petersburg and Tsarskoye Selo (which was opened for general service in 1838) were ordered abroad. Only the construction of the St. Petersburg – Moscow railroad, began in 1843, furnished the reason for the beginning of Russian locomotive building. The first locomotives for this railroad were built at the

Aleksandrovskiy Plant in 1846.

The development of the railroad network initiated modern industry. First there appeared concerns organized to meet the requirements of the railroads themselves in rails and rolling stock. In 1869, almost simultaneously, the first locomotives were produced by several Russian plants: Kolomenskiy, Nevskiy, and Votkinskiy. In the year following, 1870, the Maltsovskiy plants started producing locomotives. In the following 25 years the requirements of the railroad network could not be met by these four plants, and a considerable part of the rolling stock continued to be imported from abroad. By the end of the last century several other plants began production of locomotives: in 1892 the Bryansk Plant, in 1894 the Putilovskiy Plant, in 1897 in Khar'kov, in 1898 the Sormov Plant, and in 1900 the Lugansk Plant.

By the beginning of the XX century Russia was completely free of its former dependence on foreigners in the field of locomotive building. By that time there were also created remarkable designs for Russian locomotives, the further development of which led to the most advanced models of locomotive building.

The production of locomotives at the Russian plants from 1898 to 1917 is expressed in the following figures (Engineer P. S. Ivanov. An article on the history and statistics of Russian factory locomotive building):

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Plant	Number of Locomotives
Bryansk	2,272
Lugansk	2,116
Kolomna	2,494
Nevskiy	1,974
Putilovskiy	1,985
Sormovo	2,164
Khar'kov	2,620
Votkinskiy	439
Total	16,064

The locomotive inventory of pre-revolutionary Russia was remarkable for its unreasonable diversity of types. This was explained by the nature of the captialist economic system. Standardization of locomotive types was carried out only after the Great October Socialist Revolution.

2 ACTIVITY OF RUSSIAN LOCOMOTIVE MEN

The story of the creative activity of the founders of the domestic school of locomotive building must be broken into three stages.

The first stage is the end of the last and the beginning of the present century (A.P. Borodin, 1848 - 1898; N. P. Petrov, 1836 - 1920; M. V. Gololobov, 1870 - 1919, and others).

The second stage includes a number of years before and after the Great October Socialist Revolution (N. L. Shchukin, 1848 - 1924; A. S. Rayevskiy 1872 - 1924; B. S. Malakhovskiy, 1872 - 1934; N. I. Kartashov, 1867 - 1943, K. N. Sushkin, and many others).

The third stage covers exclusively the activities of Soviet scientists and designers (S. P. Syromyatnikov, L.S. Lebedyanskiy,

V. F. Yegorchenko, A. M. Babichkov and others).

The First Stage

Aleksandr Parfent'yevich Borodin (1848 - 1898) was one of the pioneers and founders of the Russian school of locomotive building.

In 1880, at the Kiev shops of the South-Western Railways he organized a locomotive laboratory — the first in the world. A locomotive which was the subject of the experiment, 1-2-0 type, was installed on a special stand. Two driving wheels, separated from the coupled wheels, were slightly raised above the rails, and a belt connecting the wheel with the pulley of the transmission shaft was put on the rim of the right wheel which was machined like a pulley. The power used for driving the shop lathes amounted to about 90 horsepower at 100 rpm on the driving wheels, which corresponded to a speed of 30 to 32 kilometers per hour on the rails.

In 1880 laboratory experiments were run on the use of cylinder steam jackets, in 1881 there were experiments with an engine converted to compounding. Lack of more powerful brakes precluded application of greater power. This gave A. P. Borodin the idea to utilize a rolling stand. All subsequent locomotive laboratories in Russia or abroad were equipped in accordance with Borodin's ideas, i.e. with rolling stands.

In 1886 A. P. Borodin published in a Kiev Magazine Inzhener

(Engineer) (issues 7 and 8) the results of his laboratory experiments. The experiments proved that in compound engines it was very advantageous to have more steam in low pressure cylinders than in high pressure cylinders. Under proper conditions of differential steam content the principle of compounding could result in up to 20 percent fuel economy. Subsequently this principle was utilized in all Russian and foreign locomotives with compound engines, and found very wide distribution.

A. P. Borodin was graduated from the St. Petersburg Technological Institute in 1870 and subsequently enrolled at the Institute of Communications Engineers, from which he was graduated in 1872. While still a student and considerably before the publication of the works of the Swiss engineer Mallet, he expressed an original idea about the application of the principle of compounding to locomotives. Later, in 1891, on Borodin's initiative there was built the first fast 2-2-0 locomotive with a four cylinder compounding engine which had two outside sylinders on each side located one after another (the tandem system).

For many years A. P. Borodin was the permanent chairman of all conferences and conventions of transportation engineers which were called on his initiative.

Having accepted in 1889 the post of Chief of the South-Western Railways A. P. Borodin paid a large amount of attention to the enlargement of the railroad shops, to the betterment of the material and spiritual welfare of railroad workers and employees, to the proper equipment of duty rooms for train crews and so forth. On his initiative the railroad acquired a well equipped car for dynamometer tests, which at the time was the only one in the world.

In 1896 A. P. Borodin moved to St. Petersburg where he was offered a post at the Technological Institute as a consultant to the Chair of Locomotives and Railroad Rolling Stock.

A. P. Borodin published 54 papers. In 1881 he very actively participated in starting in Kiev the monthly technical magazine Inzhener (Engineer).

One of the participants in the experiments carried out in the laboratory under A. P. Borodin's supervision was L. M. Levi. In 1893 L. M. Levi continued experiments with locomotives on the railroad track between Kiev and Fastov on the South-Western Railroad. The aim of the experiment was to study the operation of compound engines and of the use of cylinder steam jackets.

The constant position of the throttle and of the reversing mechanism was achieved through the use of the second locomotive which was placed before the experimental one and which performed the additional work which was necessary to keep the train on schedule.

The experiments indicated that the use of steam jackets does not result in any fuel economy, since when running without steam the jackets cool off rapidly, and it is necessary to use a certain additional quantity of steam to heat them.

The difficulty of maintaining constant speed with the changes in the topography of the road was responsible for the imperfection of these experiments. Later, with the subsequent development of locomotive tests, these experiments were conducted on a level roadbed with one locomotive only.

Nikolay Pavlovich Petrov was a founder of the mathematical calculation of tractive force. The list of his works includes 101 titles. His outstanding work is his hydrodynamic theory of friction. In the group of his work dealing with calculations of tractive force, his research on continuous brake systems is especially valuable. This research was published in 1878. It was first to demonstrate that the most effective braking of the train takes place on the surface where the wheels slide along the rails.

While he was a professor of the Military Engineering Academy and of the St.Petersburg Technological Institute, N. P. Petrov in 1873 organized at the Institute a Chair of Railroad Rolling Stock and for several years delivered lecture courses on locomotives. The chair, organized by N. P. Petrov, and the Institute as a whole, were of tremendous service to the country in the task of preparation of highly skilled locomotive and rolling stock railroad specialists. A. P. Borodin, N. L. Shchukin, B. S. Malakhovskiy, M. V. Gololobov and many others were outstanding alumni of the Institute.

N. P. Petrov took part in the design and construction of several types of locomotives (0-4-0 O^d, 2-2-0 P^p and others).

At the International Railroad Congress which took place in St. Petersburg in 1892 N. P. Petrov was elected president and from that time on he was a life member of the permanent International Congress Bureau.

In his speech, delivered at the meeting of the Russian Technological Society in 1899, Petrov demanded decisive measures to facilitate raising the level of education in Russia. He considered that development of philosophical thinking was necessary to engineers and technologists no less than to mathematicians, biologists, and sociologists.

Petrov applied precise mathematical analysis to the problems of the resistance of the railroad train and the safety of traffic, problems which at that time were being solved exclusively by an experimental method that was far from being accurate. He was the first to give engineering calculations of springs. Tractive force calculations, worked out by N. P. Petrov, found their application in arriving at the most profitable traffic speeds for freight trains. His last large contribution to technology was made by N. P. Petrov at the end of his long life, when he fully worked out the problems of the engineering calculation of rails. On the basis of his deductions it became possible to permit train movement at a speed of 100 versts per hour (107 kilometers per hour) in places where formerly the maximum speed was 60 versts, provided good maintenance of roadbed and of rolling stock was assured, but without increasing the weight of rails.

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After 1905 N. P. Petrov devoted much of his labor to problems of economics. In opposition to the ignorance of the ruling circles of Tsarist Russia who stood for moderation in the tempo of railroad building because of the belief, which they entertained at the time, that the railroads were losing money, Petrov in 1908 insisted on intensive railroad construction. The war of 1914 - 1918 fully affirmed the correctness of his view that the railroad network in Russia was not adequately developed.

Mikhail Vladimirovich Gololobov (1870 - 1919) was an outstanding Russian theoretician and designer. Having been graduated from the St. Petersburg Technological Institute in 1897, he was an instructor in the same Institute from 1902 to 1917 and from 1906 on he was a member of the faculty and a professor of the St. Petersburg Polytechnic Institute.

M. V. Gololobov's activity as a designer took place at the Putilovskiy Plant in St. Petersburg from 1901 to 1919. From 1906 to 1910 he was the chief of the Locomotive Bureau of the plant, and from 1910 he was a consultant on locomotive building. Under the leadership of M. V. Gololobov in the period from 1903 to 1907 there were designed and constructed four 2-3-0 U locomotives, and later in 1912 with the assistance of A. S. Rayevskiy the 2-3-0 U^u locomotive, and in 1913 - 1915 the 2-3-1 L^p locomotive.

Being a partisan of the laboratory method of locomotive testing M.V. Gololobov in 1905 constructed at the Putilovskiy Plant a testing laboratory with a rolling stand. Somewhat later the same kind of laboratory was set up by him at the Aleksandrovskiy Plant.

To M. V. Gololobov belonged the first scientific articles in the Vestnik obshchestva tekhnologov (Herald of the Society of Technologists) and in Zheleznodorozhnoye delo (Railroad Affairs) which dealt with questions of the use of superheated steam in locomotives. These articles contributed to the development of superheaters on Russian steam locomotives, in which field Russia was ahead of many countries. On his suggestion, on superheated locomotives the throttle pipe was taken out of the fire tube part of the boiler so that the steam would go directly from the dome to the superheater header. Gololobov was a distinguished and active member of the Commission on Rolling Stock and Locomotives. His premature death on 18 March 1919 represented a heavy loss to locomotive building in his country.

The first scientific monograph on the dynamics of steam locomotives was written by a professor of Moscow University D. Lebedev as far back as 1867.

In 1869 Professor Okatov conducted a series of scientific tests of passenger locomotives on the St. Petersburg – Lyuban' division.

Courses of lectures delivered by professors L. A. Yerakov, A. D. Romanov, and Ye. Ye. Nol'tein in universities and colleges, and published at the end of the last century and the beginning of the present one, have not lost their value even now.

Ye. Ye. Nol'tein was the initiator in the matter of the introduction of superheating in steam locomotives. In this great forward step, as it was noted before, Russia was ahead of many other countries, including France, England, and the United States.

The Second Stage

Nikolay Leonidovich Shchukin (1848 - 1924) was one of the leading authorities on the rolling stock of railroads. His leading progressive role in the development of locomotive building in Russia enabled him to be considered as a central figure among the specialists of his time. Having graduated from the St. Petersburg Technological Institute in 1873, Shchukin, beginning in 1875, was an instructor and then a professor of theoretical mechanics and locomotives at the same Institute. Later he was given an honorary title of Professor Emeritus.

In accordance with Shchukin's design in 1892 there was built a passenger 1-3-0 N^d locomotive with a compound engine. This locomotive after certain modifications (into series N^v) was used very extensively on Russian railroads. Shchukin was an initiator of mass construction of 1-3-1 S locomotives built on the designs of Sormovo Plant; these locomotives were the best passenger locomotives built in Russia before the Revolution. All of his principle theses and opinions which determined basic trends in Russian locomotive building were exceptionally far-sighted, and were full justified by subsequent practical experience. They will be mentioned later, in the process of describing the types of steam locomotives.

Recognizing the necessity for coordinated work in locomotive building on the part of railroad and locomotive-building plants

N. L. Shchukin was an initiator and organizer of the Commission on Rolling Stock and Locomotives. He was a permanent chairman of this Commission of the Ministry of Communications for almost twenty years. The commission effected liaison between transport and industry, the urgent need of which under the conditions of planless capitalistic economy of backward Tsarist Russia can be really appreciated only now. With the participation of the best qualified men this Commission examined all new designs of rolling stock, it was considered to be the highest Academy of rolling stock , and it was popularly known as "Shchukin's Commission". This commission in the sphere of its activity played an iminent part in the development of the rolling stock of Russian railroads. It suffices to say that during the first 15 years the commission examined over 2,200 different problems dealing with rolling stock. The activity of this commission is indissolubly tied up with the history of the development of the rolling stock of Russian railroads.

In the difficult years of the Civil War and the intervention, when the fate of the young Soviet Republic depended much upon transport, V. I. Lenin took transport under his personal supervision and by the decree of 1919 he created a special commission attached to the Council of Labor and Defence (STO). A new slogan: "All for transport" was made popular. Under the guidance of the Communist Party the working class selflessly undertook the task of reconstructing transport, and first of all, of its motive power—locomotives. There was also a need for the loyal work of direction and supervision by those people who knew transport down to the last detail. The first of the old specialists who were recruited for this responsible mission was N. L. Shchukin. In spite of his advanced age, being a patriot, loyal to his country to the end of his life, he dedicated all his efforts and knowledge to the task of reconstructing transport.

N. L. Shchukin died in Leningrad on 2 June 1924, at 76 years of age. To his memory was dedicated a special issue of Trudy Nauchno-tekhnicheskogo komiteta (Transactions of the Scientific Technical Committee) (NTK) of the People's Commissariat of Communications (1925, No 12) in which N. L. Shchukin's work after the October Revolution was noted and in which it was said: "In spite of his advanced age N. L. Shchukin energetically worked and served as an example for all who came in touch with him. His participation in the work of the NTK was especially valuable. It was N. L. Shchukin who with his own hands created and organized much in the sphere of locomotive building and maintenance, and this work of N. L. Shchukin in the NTK was most important, since he was ideologically and enthusiasticaly in favor of the necessity of having within the People's Commissariat of Communications a high scientific and technical agency of the kind which is represented by the NTK. Through the long experience of his life he came to the conclusion that the interests of transportation required an organization for scientific research work. He attempted to organize immediately after the October Revolution an experimental institute of communications, in which all complex technical problems would be completely solved through scientific research in special laboratories". N. L. Shchukin's dream did not come true during his life time on the scale of which he dreamed. That came about after his death.

Fully justified were the words of Professor I. A. Stazharov at the meeting dedicated to N. L. Shchukin's memory, when he called N. L. Shchukin "the father of Russian locomotive building."

Aleksandr Sergeyevich Rayevskiy (1872 - 1924) was an eminent Russian theoretician and designer. He was graduated from the Khar'kov Technological Institute in 1895. A. S. Rayevskiy's activity as a designer was begun at the Khar'kov Locomotive-Building Plant, where he designed 1-4-0 Shch locomotive, which were extensively used by Russian railroads. In 1910 A. S. Rayevskiy transferred to the Putilovskiy Plant. His first work at this plant consisted of design and detailed drawings of Savelyev's steam distributing mechanism which was installed on two 2-3-0 K locomotives. In 1910 and 1911 A. S. Rayevskiy was engaged in designing the conversion of 2-3-0 U locomotive to superheating (series U^{u}). At the same time, on order from the Vladikavkaz Railroad A. S. Rayevskiy began designing a four cylinder 2-3-1 L^{P} locomotive, the first design of which had a compound engine. A. S. Rayevskiy was very much attracted to this project, devoting to it much effort and labor.

After his failure at the Khar'kov Plant where the 2-3-1 semi-tank locomotive designed by him was 32 tons too heavy, A. S. Rayevskiy paid especial attention to the calculation of weights in the design of the 2-3-1 LP, in which the difference between the theoretical and the real weight was only .5 percent. Rayevskiy's next project in 1915 was the 0-5-0 (yat!) locmotive with a four cylinder compound engine. In 1916 and 1918 A. S. Rayevskiy worked on the design of the 2-3-0 U^{uu} locomotive, which was an improved type U^{u}. This prject as well as the design of the 0-5-0 (yat') locomotive was not carried out for reasons beyond his control.

After 1917 A. S. Rayevskiy worked on preliminary designs of a number of locomotives with a certain degree of standardization. This work dealt with 21 types of locomotives. This project was based on the idea of building locomotives of different types and capacities, designed for different operating conditions, but having a large number of interchangeable parts. This was the first practical attempt at standardization of locomotives. Included among the different types were those of unusual wheel arrangement in which supporting wheels were to be set between driving wheels, for instance, 2-2-1-1, which was called the Chernomorets, 1-3-1-1-0, the Belomorets, and others. Such a design, even though it permitted better placing of a wide fire box, and lowered the resistance of the tube part of the boiler to the passage of gases, because of the increased complexity of other parts of the locomotive created considerable doubts as to its soundness. The projects were examined in the Rolling Stock and Locomotives Section of the High Technical Council of the NKPS (this at the time was the name for the former Rolling Stock and Locomotives Committee) where they were subjected to very serious criticism, especially on the part of A. A. Zyablov and A. O. Chechott, as a result of which they were not carried out. Later some German plants used this idea and built some locomotives of the 1-2-1-1 type for the railroads of Turkey.

The last project of A. S. Rayevskiy was a 2-4-0 M locomotive with a three-cylinder engine. After his death the design was somewhat modified and the project was implemented. A. S. Rayevskiy combined his activity as a designer at the plant with teaching at the Leningrad Polytechnic Institute imeni M. I. Kalinin, where he occupied the post of professor.

On 20 June 1924 during testing bridges on the Oktyabr'skiy Railroad A. S. Rayevskiy was severely injured, and these injuries caused his death on 23 July in Moscow. A. S. Rayevskiy's death was a great loss to locomotive building in the USSR. The workers of the Krasnyy Putilovets Plant sent to the Moscow Station in Leningrad a locomotive festooned with ornaments. This was the locomotive of Shch type — the first one built by Rayevskiy — and it bore Rayevskiy's body to the plant.

As a theoretician A. S. Rayevskiy was of especial value to Soviet locomotive building.

While in all foreign locomotive-building plants crude empiricism was practiced in the design of locomotives, A. S. Rayevskiy, the first in the world, found a way to bring scientific foundations to designing of locomotives. He formulated scientific methods for engineering calculations of counter balances and of steam engines, he created thermic tables for boilers and for steam exhaust nozzles, tables of constant motion in the dynamic action curves of the locomotive on the road bed, tables of oscillating movements of the locomotive, and tables of wheeltrucks and he also invented an instrument fore the study of the kinematics of the link and pendulum mechanism. All these studies were presented by him in his explanatory notes, which are still being used, and which served as a foundation for the further development of the Soviet school of locomotive building.

Bronislav Sigizmundovich Malakhovskiy (1872 - 1934) was graduated from the St. Petersburg Technological Institute in 1895. His creative activity as a distinguished designer was concentrated at the Sormovo Plant. There under his guidance a 1-3-1 S locomotive was designed and constructed, which was the best monument to his memory. More about these locomotives later.

Under B. S. Malakhovskiy's direction there were also built 0-4-0 (V)[5] locomotives which were the most powerful Russian freight locomotives of the 0-4-0 type. Before the First World War B. S. Malakhovskiy formulated designes of 2-3-1 and 1-4-1 locomotives with two-cylinder engines using single expansion. In the designs boilders, cylinders, and many other parts of both locomotives were interchangeable. However, neither of these projects was carried out.

In 1915 he worked out a project for increasing the capacity of S-type locomotive to the capacity of the present Soviet passenger S^u. War interfered with the realization of this project as well. Malachovskiy was a constant member of advisory conferences of the Transport Service Engineers and of the Commission on Rolling Stock and Locomotives. During the last years of his life he worked at the Nevskiy Plant imeni V. I. Lenin in Leningrad.

Nikolay Ivanovich Kartashov (1867 - 1934) was graduated from the Khar'kov Technological Institute, specializing in locomotives. He was a student of professor P. M. Mukhachev. The pedagogical and professorial activity of N. I. Kartashov throughout his long life took place at the Tomsk Technological Institute. In 1902 he published the first scientific monograph, dealing with the methodology of experimental studies on locomotives. In 1914 N. I. Kartashov published a monograph on Locomotive Steam Distributing Mechanisms. At its time this work contained the most detailed review of all trends known to universal practice in the development of locomotive steam distribution. Unfortunately, this work did not examine the steam distributing mechanism of the Russian inventors Savelyev, Mikhaylov, Sebutov, and others.

In the period from 1919 to 1941 he published a textbook on locomotives for transport colleges. This textbook, published in six volumes, underwent several editions.

For his long and efficient work in training highly qualified specialists N. I. Kartashov was awarded the Stalin prize. Having analyzed and summed up the experience of innovators — locomotive engineers, followers of Krivonos in their operations of heavy trains, he gave this innovation a scientific foundation in his well-known work Heavy Trains which was published in 1936.

N. I. Kartashov died in Tomsk in 1943 at the age of 76.

Among well known specialists, scientists, and teachers of thisstage in the development of Soviet locomotive building the names

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V. I. Lopushinskiy, A. O. Chechott, P. M. Mukhachev, V. V. Monich, Ye. G. Kestner, P. S. Seleznev, B. I. Karchevskiy, and others must be mentioned.

Professor A. O. Chechott was a partisan of the idea of combining compounding with superheating. In his honor locomotives built on this principle, had the designation ch ($Shch^{ch}$, N^{ch}, O^{ch}, Y^{ch}, and so forth).

V. I. Lopushinskiy was a designer of many types of locomotives for the Vladikavkaz Railroad. But his best achievement was his direct participation in the construction of 0-5-0 E locomotives.

Great inventive thought was manifested by A. A. Zyablov. His by-pass devices are well known; they were widely used before the appearance of Trofimov's piston valves. To Zyablov and Bashkin also belongs the design of injectors which operate without the loss of water.

The Third Stage

The Great October Socialist Revolution opened great vistas to advanced ideas of Soviet locomotive building — ideas the foundations for which were already laid down in the scientific and practical achievements of the foregoing stages.

In the first years of the Soviet regime the questions of immediate reconstruction of railroad transport assumed the character of a basic problem. This was indicated in the decisions of the XI Congress of the VKP (b) which represents a historical landmark on the way to the development and technical enrichment of Soviet railroad transport.

Speaking at the VIII All-Russian Congress of Soviets on 22 December 1920 V. I. Lenin ardently supported the Five-Year Plan for reconstruction of locomotive inventory and the locomotive-building industry, which was prepared by the NKPS under the direction of F. E. Dzerzhinskiy. Lenin said then that because of the enthusiasm of workers rebuilding of locomotive inventory would be completed in $3\frac{1}{2}$ years.

Because of the efforts of the Party and the Government after the conclusion of the Civil War the work of reconstruction of transport progressed rapidly. In 1924 the XIII Party Conference stated that railroad transport could take care of all the requirements of the national economy.

The policy carried out by the Party and the Government in the field of planned development of the socialist economy of the country in the years of the Stalin Five-Year Plans had a decisive effect in the development of Soviet locomotive building.

The growth of all phases of the national economy, unprecedented in history, led to a considerable increase in railroad freight carried. In spite of several measures taken to strengthen railroad transport in the First Five-Year Plan, at first transport did not keep up with the tempo of development of the national economy, and drastic measures had to be taken to improve its operation. At the SVI Congress of the VKP (b) in July 1930 Comrade Stalin pointed out the necessity of taking hold of transport in a Bolshevik manner and pushing it forward.

In accordance with the decisions of the SVII Congress of the VKP (b) a program was adopted which called for the technical improvement and reconstruction of railroad transport during the Second Five-Year Plant (see the stenographic report of the SVII Congress of VKP (b), page 664).

This program provided for increasing the railway network, laying heavy rails, changing to gravel roadbed ballast, introducing automatic block signals, conversion of freight trains to completely automatic braking, mass introduction of automatic coupling, and construction of freight cars of larger capacities. It was planned to increase the locomotive inventory from 19,500 units in 1932 to 24,600 units in 1937 with a simultaneous transition to more powerful and modern types of locomotives. The FD locomotive with a power rating up to 3,000 horsepower became in the Second Five-Year Plan the basic type of freight locomotive inventory, and the IS locomotive with the same power rating became the basic type of passenger locomotive.

In the beginning of 1935 the Party put L. M. Kaganovich in charge of railroad transport, who succeeded in introducing Bolshevik methods in the work of transport. On the basis of the historic order No 183 Ts dated 7 August 1935, concerning improvement in the operation of locomotives, a complete reorganization of locomotive repair was effected.

Under the guidance of the People's Commissar of Heavy Industry, G. K. Ordzhonikidze, the existing Soviet locomotive-building plants were enlarged and modernized and by 1934 a gigantic enterprise, the child of the first Five-Year Plan — the Locomotive Building Plant imeni October Revolution, which is one of the foremost plants in the world in production and technical modernization, began operation. Comrade Ordzhonikidze set before the industry a task of tremendous importance: cutting down on imported equipment. This requirement was directly reflected in Soviet locomotive building. Powerful locomotives were built completely of Soviet materials and with Soviet equipment. Introduction of rolling of steel plates 140 - 160 millimeters thick permitted manufacturing steel plate frames, which in turn provided for the mass building of more powerful and modern FD and IS locomotives.

The history-making decision of the Party and of the Government and the personal directions of Comrade Stalin resulted in the complete technicalchangeover of locomotive inventory of the Soviet railroads and its substantial improvement both in quantity and in quality, especially in the period between the XVII and XVIII Congresses of the Party, when railroad transport became one of the most advanced and progressive branches of the national economy.

Railroad freight hauled during these years increased as follows (in billions of ton-kilomters):

1933	1934	1935	1936	1937	1938	1938 in percantage of 1933
169.5	205.7	258.1	323.4	354.8	359.1	217.7

(From Comrade Stalin's report to the XVIII Party Congress (I. V. Stalin, Problems of Leninism, 1947, page 585.).)

In 1948 railroad freight hauled increased in comparison with 1947 by 27 percent and exceeded the level of the prewar year of 1940.

Requirements presented by the development of the national economy favorably affected the creativeness of talented Soviet scientists and designers -- the builders of Soviet locomotives. Among them we must note first of all the leading role of the Chief Designer of the Kolomna Plant, the recipient of the Stalin Prize, Lev Sergeyevich Lebedyanskiy. All the best Soviet locomotives, in the order of their production, were built with the participation, and later under the direct guidance, of L. S. Lebedyanskiy. Of the latter the 2-3-2 express locomotives (Figures 72 and 73) and the 1-5-0 freight locomotives must be noted (Figure 31). A group of designers works under the supervision of L. S. Lebedyanskiy, among which the following should be noted: G. A. Zhilin, V. K. Chistov, D. V. L'vov, V. D. Utkin, and V. D. D'yakov. Among older designers of the plant was K. N. Sushkin, under whose leadership the S^u locomotive was designed.

Connected with locomotive building at Kolomna Plant are the names of younger distinguished designers, who formerly worked at the plant: A. A. Chikov, who now is a Doctor of Technical Sciences and a Professor of the MEMIIT; Stalin Prize Winner M. N. Shchukin;

Candidate of Technical Sciences V. V. Filippov; A. V. Slomyanskiy; and many others.

For the introduction of the conveyer method in Soviet locomotive building several engineers of the Kolomna Plant, K. K. Yakovlev, I. M. Shakhray, P. P. Arkhimenko, M. P. Gridnev, A. V. Shadrin, A. P. Stepanov, V. A. Il'yashevich, Ye. F. Gorin, and I. A. Kholodilin were honored with the Stalin Prize.

In capacity and modernity of technical equipment and facilities, the leading position, as a production concern, belongs to the Voroshilovgrad Plant imeni October Revolution. Its design bureau, headed by M. N. Anikeyev, produced several designs, among which may be mentioned designs of a 2-3-2 express train, the author of which was P. A. Soroka and which was built in 1938 (Figure 74); and of the 1-5-2 freight locomotive with a completely new and unique engine having in each of the two cylinders two pistons which move in opposite directions (Figure 33).

In no other country is electric arc welding so extensively applied in locomotive building as in the USSR. The use of acetylente-oxygen welding in locomotive boiler construction was started in the USSR as far back as 1919-1921. Introduction of electric arc welding took place in 1930. In 1932, at the Kolomna Plant, on the initiative of Engineer M. N. Goluzin, under the supervision of K. N. Sushkin, Engineer V. V. Filippov designed for the first time in the world an all-welded locomotive boiler, which was installed in a narrow gauge locomotive of the 159 type. Efficient operation of this boiler served as the start of extensive application of electric welding.

Since 1933, fireboxes for E^m, S^u, FD, and IS locomotives have been only all-welded construction (except for the staybolts), and since 1935 the outside sheets of fireboxes have also been welded. In 1938 the Voroshilovgrad plant built a large number of FD locomotives with all-welded boilers. Only the seam connecting the outside sheet of the firebox with the tube part of the boiler was riveted.

Soviet industry now builds locomotives only with all-welded boilers. Electric welding in the USSR occupies first place in world locomotive building, both in its technical progress and in the number of all-welded boilers produced, which is over 1,000.

Soviet designing experience was most fully and scientifically described in the description of the process of designing and construction of the FD locomotive. This published work was produced by a group of authors. Although some parts of this work at present are already obsolete, this published work still gives the most complete treatment of modern methods of locomotive design.

The FD locomotive (Figure 30) itself was a subject of systematic scientific study and tests; dynamic tests of the frame and of the stresses on the driving gear were unique and they were the most thorough ones in the world.

Soviet methods of designing locomotives are much in advance of foreign, and, especially, of American methods. The efficiency of Soviet locomotives, as a rule, is 10 to 15 percent higher than the efficiency of American locomotives of equal power rating.

The founder of locomotive thermal technology is an Academician and a recipient of the Stalin Prize Sergey Petrovich Syromyatnikov. He formed a whole school of Soviet locomotive specialists and he trained many scientific workers and engineers.

S. P. Syromyatnikov's first work on thermal processes in the locomotive boiler and of the superheater, based on general theoretical precepts of thermal technology and on the summing up of results of experiments with different types of locomotives, was published in 1923. At the same time there appeared a number of his magazine articles. In subsequent editions this capital work was enlarged and modernized on the basis of creative life-long experience, and at present it serves as a basis for all engineering calculations for thermal values of locomotives both in designing of new locomotives and in modernizing the existing ones. This work also gave a scientific basis for searching for the most efficient, methods of locomotive operation.

Recently under the leadership of S. P. Syromyatnikov a group of members of the Locmotive Division of the Moscow Order (of the Red Banner of Labor , Electro-Mechanical Institute of Engineers of Railroad Transport imeni F. E. Dzerzhinskiy (MEMIIT)) designed a 1-5-1 type locomotive, completely modernized. In its power characteristics this locomotive is close to the FD locomotive, but its boiler is of altogether different design. The firebox has no combustion chamber, the tube section is considerably shortened, and gases leaving the tube section have temperatures of 800 - 850 degrees Centigrade. Their heat will be used in two steps — first in the steam superheater, and then in the air heater. This permits full efficiency of 10.5 to 11 percent, in other words, this locomotive with steam pressure of 15 atmospheres will be the most economical in the world. This locomotive will be built by the Voroshilovgrad Plant.

Professor N.I. Belokon' published in 1933 - 1938 a series of papers on the locomotive thermal process. In this work the results of experiments and of interdependence, based on the theory of analogy, were used. The same scientific method was adopted in several experiments using thermic models, which were carried out during the last ten years in the laboratories of the MEMIIT.

The methods of S. P. Syromyatnikov and N. I. Belokon' in their essence are different, but they supplement each other and permit an approach to the solution of the same problems from different starting points, thus serving as checks on each other.

A number of very important problems of design and theory of locomotives, locomotive operation, and overhaul was studied and solved by many Soviet scientists -- workers of the Central Scientific Research Institute MPS (TsNII), of transport technical colleges, of [illegible], plants and railroads - whose names are widely and justly known. Among them are the merited scientist and technologist Professor [illegible]; Professor K.A. Shishkin; Doctors of Technical Sciences and Professors A.A. Chirkov, A.M. Godytskiy-Tsvirko, [illegible] Ivanov, P.K. Konakov, and P.A. Slitkov; Candidates of Technical Sciences [illegible] Grinenko, V.V. Ivanov, S.M. Kurherenko, A.P. [illegible], and A. [illegible] Yevtushenko, V.M. Panskiy, K.P. Korolev, [illegible], [illegible] Mishkin, S.S. Zol'nikov, I.V. Pirin, A.V. [illegible], [illegible] Sharonin, N.I. Dorokhin, B.D. Podshivalov, [illegible], and others.

The founders of the science of the tractive force of locomotives were Soviet scientists A.M. Babichkov and V.F. Yegorchenko.

A merited worker of science and technology Doctor of Technical Sciences Professor A.M. Babichkov published in 1928 in collaboration with Professor [illegible] a paper on The Selection of Basic Dimensions Characteristics of Locomotives, which was a fundamental work in this sphere. A.M. Babichkov published together about 30 works. In recent editions of the textbooks for transport colleges, <u>Tractive Force of Locomotives,</u> which were prepared by Babichkov in collaboration with Yegorchenko, there is much valuable information, especially in the field of express trains. Almost all of the important test of tractive force in the prewar years were carried out under the direction of Babichkov.

[illegible] has been engaged in teaching activity for a number of years and at present he is a professor of MEMIIT.

Doctor of Technical Sciences Professor V.F. Yegorchenko was one of the organizers of the Scientific Experimental Institute of the MPS, which, after several reorganizations, developed into the Central Scientific Research Institute of Railroad Transport (TsNII MPS). Under V.F. Yegorchenko's direction E[illegible], C[illegible], M, FD, and SO locomotives were tested, as well as the brake systems designed by Kazantsev and [illegible]. The [illegible] activity of V.F. Yegorchenko in the field of railroad transport touched upon almost all the basic elements of traction -- locomotives, brakes and automatic coupling.

Being opposed to the idea of employing Carratt locomotives on Soviet railroads, which idea was popular at the time, Yegerchenko was one of the initiators of the introduction of freight locomotives of 1-5-1 SO type. Traction tests and their scientific elaboration were carried out by Professor O.N. Isaakyan, Candidate of Technical Sciences [illegible], [illegible], P.A. Gurskiy, Docent B.A.Pavlov, and others. Professor O.N. Isaakyan worked out the theoretical problems of calculating tractive force on the basis of the boiler, a method of determining efficiency taking into consideration consumption, and a number of other problems. Several questions of practical thermal technology such as tests with fuel oil and tests with mechanical stokers, and others, were examined by A.Z. Tsygankov, [illegible], [illegible], and others.

There are two methods in the history of the development of experimental research on locomotives. The first one was the road method, that is on the actual run of the experimental train, and

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the other method was the laboratory one.

On 1[illegible] June 191[illegible] at the Ministry of Communications there was set up a scientific research institute for testing locomotives. This institute -- the only one in the world -- was called Tests of Types of Locomotives. Tests were carried out only on the road. The results of these tests had a tremendous value for removing defects in existing locomotives, and for introducing the most efficient methods of locomotive operation, and the results were also used in the design of new types.

Now this school of scientific experiments is headed by professors [illegible].F. Yegorchenko, A.M. Babichkov, O.N. Isaakyan and Candidate of Technical

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Sciences P. A. Gurskiy.

The idea of the laboratory method of locomotive testing was born, as we have seen, in Russia as far back as the eighties of the last century (A. P. Borodin). Since that time several laboratories have been set up in our country and abroad.

Two laboratories were organized in St. Petersburg by M. V. Goloboboy, who was a partisan of laboratory testing; one was opened at the Putilovskiy Plant in 1905, and the ohter, somewhat later, at the Aleksandrovskiy Plant. Neither laboratory is in existence now, since their imperfect equipment, and the overheating of the rolling stand did not permit conducting tests at high speed. However, the program of liquidating the laboratory at the Proletarskiy Plant, which in 1930 was turned over to the Leningrad Institute of Railroad Transport Engineers, must be acknowledged a mistake.

In order to improve road testing, in 1932 near the Shcherbinka station in the vicinity of Moscow an experimental ring, 6 kilometers in circumference, was built. The TsNII MPS is in charge of this ring, on which at present all locomotive tests are carried out. Ring tests afford great convenience, since they obviate the need of selecting special sections of the road with the same topography.

However, complete scientific research on locomotives must be combined in method, i. e. it must combine road tests and laboratory tests.

The first tests are less accurate, but they fully satisfy practical experience of operation. The second kind permits precise scientific study of operation of many mechanism of locomotive and serves the purpose of further improvement of the latter. For instance, in a laboratory it is possible to conduct dynamic studies of mechanism, and the research on the influence of elements of steam distribution on operation of the engine, and many others.

A decision of the Government provided for the construction of the central testing laboratory equipped with rolling station and the stands necessary for complete and all-around testing of locomotives of any size, power rating and type.

The Party and the Government created all the conditions necessary for the training of the new Soviet locomotive specialist personnel. An enormous role in this matter was played by many institutions of higher learning in our country: the Moscow Ordena Trudovogo Krasnogo Znameni (Red Banner of Labor decoration) Electro-Mechanical Institute of Railroad Transport Engineers imeni F. E. Dzerzhinskiy, the Krasnoznamenyy (Red Banner) Mechanical and Machine-Building Institute imeni Bauman, the Leningrad Ordena Lenina (Order of Lenin decoration) Institute of Railroad Transport Engineers, and others.

Comrade Stalin, in his report to the XVIII Congress of VKP (b), gave the following figures describing the number of transport and communications engineers graduated by the schools during several years:

Years	Number of Engineers of Transport and Communications Graduated During the Year (in thousands)[1]	Years	Number of Engineers
1933	1.8	1936	6.6
1934	4.0	1937	7.0
1935	7.6	1938	6.1

[1] I. V. Stalin, Problems of Leninism, 1947, page 588.

Together with scientific achievements, Soviet locomotive practical experience was also enriched by many inventions and innovations. As far back as 1908 I. O. Trofimov invented, and in 1924 improved, a spreading valve, which is a combination of a pistol valve with the most efficient by-passing device. These spreading valves are now an integral part of almost all Soviet locomotives with internal steam inlet.

The creative activity of invention and innovation in the field of locomotives after the death of I. O. Trofimov was continued by his sons who at present are working on designs for injectors of fresh and exhaust steam. Test models of Trofimov injectors of the latest design gave excellent results. It should be assumed that these injectors will find wide application in our locomotives, contributing to the economy of their operation.

Of great value were the inventions of new types of Soviet automatic brakes designed by F. P. Kazantsev and I. K. Matrosov,

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and automatic coupling.

The design of a chamber superheater, installed on one experimental locomotive, suggested by Candidate of Technical Sciences I. V. Pirin, (Figure 24), is exceptionally interesting. This locomotive is referred to in greater detail in other chapters later in the book. Construction of several locomotives equipped with superheaters of this type is scheduled in the near future.

Engineers I. A. Azarov and N. I. Krasnobayev proposed a very simple system of valve steam distribution.

Engineer R.chkov designed and improved a coal stoker which in its design and operation is superior to the American stoking systems. Many other valuable innovations in locomotive operation were introduced by Soviet inventors.

A tremendous role in the development of the railroad transport and, specifically, in the locomotive field and locomotive exploitation was played by the Stakhanovite movement.

Many common people, never heard of before, once they were awakened to the struggle for improved efficiency in operation of locomotives, demonstrated by action that many important factors which determine the manner of operation, and first of all tables for steam feeding and tractive force, were unduly low and obsolete. Going beyond the set limits served to indicate what tremendous internal assets were hidden in the existing locomotive inventory.

A locomotive engineer (driver) of the Slavyansk Station, P. F. Krivonos, having studied the locomotive and mastered the technique of running trains, in 1935 started to run heavy trains driven by E locomotives with the average technical speed of 42 kilometers per hour instead of 23 kilometers per hour, as directed by the schedule, and he increased the boiler pressure to 50 kilograms/square meter/hour instead of 33-40 kilograms/square meter/hour, which was the previous practice. The initiative of P. F. Krivonos, who now is a Hero of Socialist Labor, was soon followed by many leading locomotive drivers.

The following names of leading locomotive (drivers) in the country, recipient of the Stalin award of Hero of Socialist Labor should be mentioned: N. A. Lunin, I. T. Solov'yev, D. A. Korobkov, I. P. Balenin, A. P. Papavin, I. P. Blinov, N. A. Oshats, E. K. Katschen, [illegible] Shumilov, B. K. Mezhetskiy, and others.

A solemn reception of railroad workers by Comrade Stalin took place in Kremlin on 30 July 1935. Appreciating the role of the railroad transport in the USSR Comrade Stalin called our country a great railroad power.

Training of remarkable locomotive engineer personnel who expertly mastered the technique of running trains, repairing and maintenance of locomotives, provided for the improvement in all respects in the operation of railroad transport.

As a result, daily carloading grew from 50-55 thousands in 1934 to 110 thousands in 1940. Divisional speed of freight trains from 13-14 kilometers per hour grew by 1940 to 20 kilometers per hour.

As for the importance of doing away with the blind infatuation with limits which reigned in the sphere of railroad transport and hindered its development, Comrade Stalin, speaking at the First All Union Conference of Stakhanovites, said:

"Take, for instance, the People's Commissariat of Communications. In the central agency of this Commissariat there were recently a group of professors, engineers, and other specialists; among them there were Communists, too. This group was trying to persuade everybody that the commercial speed of 13-14 kilometers was a limit beyond which one could not move, if he did not want to come in conflict with "the science of exploitation". This was a fairly authoritative group which preached its views both verbally and in print, gave instructions to other agencies of the NKPS, and in general dominated the thoughts of operations personnel. We, who were not specialists in this line, were in turn, trying to persuade these erudite professors on the basis of suggestions by numerous men of practical experience in railroading, that 13-14 kilometers could not be the limit, that with a certain organization this limit could be pushed further. In answer to this, this group, instead of heeding the voice of practical experience and of reexamining its attitude towards the matter threw itself into fight against the progressive elements of railroading and intensified the propaganda of its conservative views even more. It is easy to understand that we were forced to hit these esteemed people in the teeth slightly and politely escort them out of the central agency of the NKPS (Applause) And now what? Now we have commercial speed of 18-19 kilometers per hour (Applause)." (I. V. Stalin, Problems of Leninism, 1947, pages 504-505).

The introduction of new technical standards and of the new technological process in the overhaul and operation of locomotives, which was implemented on the basis of the history making Order

Number 78/4 dated 28 May 1936, raised the level of the work of Stakhanovites-Krivonosovites and led to the more intensive operation of the railroad rolling stock.

The development of Stakhanovite-Krivonosovite movement among transport men presented locomotive specialists with the task of improving old type locomotives and building of new locomotives which would be more powerful and faster than the existing ones and economical in fuel consumption and the cost of repairs. This could be achieved with the increase of tractive force, the increase of grate area, high degree of superheating of two-cylinder single expansion engines, and correct selection of basing operational characteristics. In addition, reinforcing the roadbed afforded an opportunity to design a locomotive of a simpler form and a shorter length.

High forms of labor organization played an important role during the Great Patriotic War also. Due to its rich technical equipment and efficient utilization of the latter the railroad transport honorably fulfilled those very responsible and complex tasks which were imposed upon it during the last war. In his report on the occasion of the XXVII anniversary of the Great October Socialist Revolution on 6 November 1944, Comrade Stalin evaluated the work of railroad transport during the Great Patriotic War in the following words: "Soviet railroad transport stood a load which could hardly have been handled by the transport of any other country." (I. V. Stalin, On the Great Patriotic War of the Soviet Union, Gospolitizdat, 1946, page 158).

In reviewing the whole course of the development of locomotive building in the USSR for the last 30 some-odd years, we must note two of its periods -- before the First Stalin Five-Year Plan and after it.

Until 1931 only 0-5' E^{u} locomotive was built for freight service. Intrinsically, it was a successful locomotive, both in design and thermo-technical aspect. However, the need to increase the weight of trains and the speed of traffic in the near future because of a constantly rising amount of freight traffic together with the need to installing automatic coupling and an over-all braking system on freight trains, required construction of more powerful locomotives.

The average running speed of freight trains by years is given in Table 1.

A considerable increase in running speeds by the end of the Second Five-Year Plan was achieved by the introduction of faster 1-5-1 and 1-5-0 locomotives, by the growth of the Stakhanovite-Krivonosovite movement, and by other factors in the process of reconstruction of transport, which have already been mentioned.

[See Tables 1 and 2 on next page]

During the three prewar Stalin Five-Year Plans railroad transport acquired 11,852 locomotives. Under the 1946-1950 plan it will receive additional 6165 new locomotives.

The saving on locomotive fuel consumption is the most important source for lowering the cost of haulage. How great the cost of locomotive fuel is can be seen from Table 3 which lists average figures for funds spent by railroads on locomotive operation.

TABLE 1

Average Running Division Speed of Freight Trains by

Years in Kilometer-Hours

1913	1929	1932	1934	1935	1937	1940
[illegible]	[illegible]	14.3	14.2	15.6	18.3	20.3

(Taken from L. Ya. Vol'fson, V. I. Leodovskiy, N. S. Shil'nikov. Economics of Transport. Railroad Transport Publishing House, pages 397, to 409.)

The increase in the number of steam locomotives on the railroad network in the period from 1928 to 1940 is represented in percent in Table 2.

TABLE 2

Number of Locomotives by Years (in Percent)

Locomotive Series	1928	1934	1937	1940
Freight				
FD	0	1.2	9.5	14.5
SO	0	0	3.5	18.9
E	25.5	41.9	40.2	37.3
Other	74.5	56.9	46.8	29.3
Passenger				
IS		0.1	2.7	12.0
S^u	16.8	29.9	42.4	48.5
Other	83.2	70.0	54.9	39.5

(V. S. Sharonin. Locomotive economics during the 30 years of Soviet Power. Tekhnika zheleznykh dorog (Technology of Railroads), 1947, volumes 11-12, pages 9-14.

TABLE 3

Average Costs of Locomotive Operations

Item of Expense	FD Locomotive: In rubbles Per Year	FD Locomotive: In rubbles Per 10 th km Gross	%	E^m locomotive: In rubbles Per Year	E^m locomotive: In rubbles Per 10 th km Gross	%
Fuel	270,000	23 r 10 k	54.5	122,500	21 r 10 k	49.2
Repair and overhaul of all kinds	126,500	10 r 72 k	25.3	61,400	10 r 51 k	24.7
Crew Wages	70,500	6 r 03 k	14.20	50,500	8 r 71 k	20.2
Lubrication and lighting	6,240	70 k	1.65	3,880	67 k	1.55
Water	14,050	1 r 20 k	2.82	6,960	1 r 20 k	2.80
Amortization	7,560	65 k	1.53	3,850	67 k	1.55
Total	494,850	42 r 40 k	100 %	249,090	42.94 k	100 %

(Table 3 submitted by Professor A. A. Chirkov and published with his permission)

From this table it can be seen that the cost of fuel comprises about half of all railroad expenses. Decreasing fuel consumption by just 1 percent saves the State hundred of millions of rubles.

That is why, in the process of designing new, more powerful and modern main line locomotives, locomotive building technology aims to find new ways to make locomotives more economic thermic prime movers. Generally, these new ways are found by installing water and air preheaters, by raising the degree of steam superheating, by improving steam feeding systems, straightening steam passages in the cylinders, increasing steam chests, improving the tractive system, etc. No less important is the higher degree of maintenance and repair dependability of locomotives, achieved through the use of high quality steels, roller bearings, wear resistant parts, etc.

All the above-mentioned technical measures are applicable not only to newly built locomotives, but can also be successfully applied to the already existing locomotives by modernizing the latter. Many of these elements of modernization have already been used and are periodically used, such as, for instance, different designs of feed-water heaters, air heaters, and so forth. However, in the majority of cases, there designs were not perfect from defects, and consequently they did not receive approval in practical operation. Soviet inventive and designing thought must insure the success of these technical measures in the near future.

The decrease in multiplicity of types and series of locomotives, implemented during the years of Soviet power and the introduction of a small number of standard types of different series (E, SO, L, FD, S^{u}, IS) considerably affect the reduction in delivery prices on locomotives, reduction in the cost of repair and overhaul and expenses for spare parts, etc. For instance, the cost of locomotives built serially is 2 or 3 times lower than when only a single locomotive or only a few locomotives of one type are built.

Locomotive delivery prices for the beginning of 1941 are given in Table 4.

Locomotive-Building Industry Delivery Prices On Locomotives at the Beginning of 1941[1]

Series	Price of Locomotive and Tender, Empty, in Rubles	Weight of Locomotive and Tender, Empty, in Tons	Price Per Ton of Weight of Locomotive and Tender, in Rubles
E[m]	135,000	95.7	1,410
SO 17	170,000	111.0	1,530
SO 19	390,000[2]	143.0	2,725
FD	265,000	176.6	1,510

[1] V. N. Orlov, V. V. Povorozhenko, Technical Calculation and Economic Accounting in the organization of railroad transportation. M. 1943, page 139

[2] Book of collected articles; Basic Problems of the Five-Year Plan, 1947.

The average service life of a locomotive is estimated at 35-40 years, and the precise determination of the service life is subject for many economic studies. The cost of all kinds of repair and overhaul during 2 - 2.5 years on the average equals the initial cost of the locomotives. In 15 years as much metal is spent on the overhaul as there is in the locomotive initially.

According to latest research dealing with the selection of types of locomotives for the near future, new 1-5-0 locomotives are planned with characteristics similar to the characteristics of the L series of locomotives with weight of 90 tons on the drivers, and a weight of 18 tons on a pair of drivers, and the FD (modernized) with a weight of 112 tons on the drivers, and a weight of up to 23 tons on a pair of drivers. These planned types are much more eoncomical than their prototypes SO and FD. Therefore, it must be assumed that their introduction in large numbers will take place in the near future.

Further, the high degree of economy of 1-5-2 locomotive with weight of 135 tons on drivers and a weight of 27 tons on a pair of drivers, is becoming quite apparent. This locomotive, starting with a freight haulage of 6 million ton-kilometer/kilometer, is much more profitable in operation than the modernized FD[u]. Therefore, there are reasons for assuming that the 1-5-2 locomotive with a weight of 27 tons on a pair of drivers, has a definite chance of being used on the railway network of the USSR. (Problems in the Economy of Railroad Transport, Transzheldorizdat, 1948.) As for passenger locomotives, a 2-4-2 type with a weight of 18 tons on a pair of drivers is planned.

On the busiest main railways, the electrification of a part of which is planned, with a freight traffic of 7-8 million ton-kilometer/kilometer under average conditions of contour and cost of fuel, steam locomotive operation will be more profitable than electric operation. Many divisions of our railway network, the ones with easy contours and low cost of coal, can, in spite of enormous freight traffic -- up to 18-20 million ton-kilometer/kilomter -- be very efficiently operated with steam locomotives. A suitable type for this is a 1-5-2 locomotive with a total weight of 135 tons on the

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drivers. On easy contours such a locomotive would permit running trains with a weight of up to 6000 tons, on medium contours - 2500-3000 tons and on difficult - 2000-2500. The most profitable speeds on standard grades are within the limits of 20-30 kilometers per hour.

The steam locomotive, which, since the start of railroads and up to the present time has been a basic kind of locomotive, will remain as such for many more years to come. Other kinds of locomotives - electric, Diesel, and gas turbine - which are being developed more and more, so far are participating in railroad transport much less than steam locomotives.

PHOTOGRAPHS

Between pages 4 and 5 of original text

Upper Left: A. P. Borodin

Upper Right: N. P. Petrov

Bottom: N. V. Cololobov

Between pages 8 and 9 of original text

Upper left: N. L. Shchukin

Upper right: A. S. Rayevskiy

Bottom: B. S. Malakhovskiy

Between pages 12 and 13 of original text

Upper left: L. S. Lebedyanskiy

Upper right: N. I. Kartashov

Bottom: S. P. Syromyatnikov

Between pages 16 and 17 of original text

Upper left: I. I. Nikolayev

Upper right: A. M. Babichkov

Bottom: V. F. Yegorchenko

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CHAPTER II.

FREIGHT STEAM LOCOMOTIVES

3. GENERAL REVIEW

The amount of freight to be hauled, the average distance of haulage and the technical state of the equipment are the factors which play a decisive part in determining the weight of the trains and the average working speeds. On the basis of these data the power rating of a locomotive is determined, and the most important factors in the power rating of a locomotive are its tractive force and its grate area.

In the process of building locomotives not so long ago the first question to be settled was: should it be build with the front truck or without it? There was an opinion that in freight service the front truck is nothing but dead weight, that on the up-grade run its additional weight causes shortening of the train, and on the down grade it is useless because the speed of the train is, after all, limited by the action of the brakes. This was one of the conservative arguments which ignored the demands for increased speed.

N.L. Shchukin, who advocated the use of the front truck on freight locomotives, so as to permit increase in the size of the boiler and of the grate area, was fighting for increased speeds of freight trains. That he was right in his opinion was proved as far back as 1915. Engineering calculations based on the standards of operation of that period indicated that with five coupled wheel pairs and with a front truck the total weight of the locomotives was increased only by 12 percent, while its speed under maximum draft increased by 21.5 percent. These calculations were fully confirmed in actual operation of 1-5-0 Ye locomotives (Figures 22 and 23) and 0-5-0 E locomotives (Figure 15).

Even more convincing is the comparison of E^m and SO locomotives (Figures 17 and 27). With the same engine and practically the same tractive force SO locomotives with the same train weight on the maximum grade gave 50 percent more speed.

The effect of trucks on the speed of freight locomotives is clearly demonstrated by the following figures which represent speeds on standard grades with identical tractive boiler operation, specific steam consumption, ratio of weight to power, and adhesion coefficients (Locomotives, edited by Academician S.P. Syromyatnikov and Professor A. Chirkov, Transzheldorizdat, 1949, page 38);

Locomotive	Speed on Up-Grade	Percent
0-5-0	20.3	100
1-5-0	23.3	115
1-5-1	25.3	125
1-5-2	29.3	145

To justify their conclusions in favor of locomotives of 0-4-0 and 0-5-0 types, conservative opinion usually employed the comparison of O^v, Y^{ch} and E (Figures 2 and 15) with the 1-4-0 Shch locomotive having low efficiency. But this example could not, however, serve as a basis for a general conclusion; it was applicable to an individual case only.

The increase of tractive force was accomplished in 2 ways -- by means of an increase in the number of drivers and by means of the increase of the load of a pair of drivers upon the rails. After changing from four driving pairs of wheels to five the increase of tractive force was accomplished only through the increase of the load upon the rails.

Practical experience served to establish that so far five driving pairs of wheels in a rigid frame represent a limit. All attempts to increase the number of driving axles to 6, and especially to 7, were unsuccessful. In these attempts considerable obstacles were encountered in the operation of locomotives on curves, and not only because of the difficulty of intertwining all wheel pairs on the curved track, but also because of the decrease of adhesion which led to incomplete use of tractive force; furthermore, the work of coupling rods was also made more difficult. Whenever it is necessary to increase the number of driving axles above 5, it was necessary to change to articulated, more complex locomotives.

The change from E^u to FD locomotive (Figures 16 and 30) was also a transition from a load of 17 tons to a load of 20 tons.

In accordance with the decisions of the XVII Congress of the VKP (b) the FD locomotive became the basic unit of the freight locomotive inventory on the most important reconstructed main lines, and, being soon used in large numbers, it displaced the E locomotive from the main lines.

1-5-0 SO locomotives (Figure 27) at first were designed for a load on the rails of 17 tons. The installation on them of steam condensation equipment raised the load to 19 tons (Figure 28). A number of SO locomotives, which do not have this equipment, but which are equipped with the fan draft, are of 18 ton loads. The 1-5-0 L locomotives built at the Kolomna plant are of the same load (Figure 31).

The relation between the load transmitted from a pair of drivers to the rails and the type of rails is determined by a coefficient which represents the ratio of the weight of a linear meter of rail in kolograms to the load in tons exerted upon the rails by a pair of drivers. By means of calculation it was determined that the optimum value of this coefficient is within the limits of 2.2 - 2.4. This coefficient and the type of rails determine the permissible loads upon the rails from a pair of drivers.

Table 5

Suggested Loads from a Pair of Drivers upon the Rails

Type of Rails	Weight of 1 linear meter of rail in kilograms	Load upon the Rails from one pair of drivers in tons K = 2.2	K = 2.4
R 30 (IVa)	30.9	14.1	12.9
R 33 (III a)	33.5	15.2	14.0
R 38 (II a)	38.4	17.5	16.0
R 43 (I a)	43.6	19.8	18.2
R 50	50.0	22.8	20.8
R 65	65.0	29.5	27.1

This table is taken from the book Parovozy (Steam Locomotives), General Course on Designs and Elements of Theory, edited by the Academician S.P. Syromyatnikov and Professor A.A. Chirkov, 1949, page 29.

The immense amount of metal needed and the tremendous cost dictate the necessity of precise research for the selection of types of rails and makes this one of the problems of national importance.

R 43 and R 50 types of rails will continue to be used for the tracks of our railway system; on main lines with the heaviest traffic the rail will be R 65.

In the beginning of reconstruction of our railroad transportation (1930-1931) ten sample steam locomotives of 1-5-1 T^b and 1-5-2 T^a types with a load from a pair of drivers on rails of 23 tons were ordered from abroad.

T^a and T^b arrived at the port of Leningrad in October 1931 and they were assembled at the Proletarskiy Locomotive Repair Shops. These locomotives proved uneconomical.

The experience of their operation indicated that it would be wise to refrain temporarily from applying the load of 23 tons on rails until the roadbed was adequately reconstructed. By the time these locomotives arrived there was already built in the USSR the first Soviet locomotive of the powerful FD type, which was considerably more economical and required a load upon the rails which was satisfactory under the existing conditions.

The rapid accumulation of exprience resulting from the operation of FD locomotives permitted their introduction into service in large numbers, and thus the problem of providing our transportation with advanced technical equipment was solved.

Together with the above mentioned achievements certain failures may be mentioned.

Locomotives which are designed and built in disregard of practical economic and technical conditions usually have very little value in practical application. This is clearly proved by the following facts.

In 1928-1932 there were a group of specialists who waged a campaign for the use in mass quantities on the USSR railway system of

Garrat locomotives. One Garrat locomotive, ordered on their insistence from England, arrived in the USSR in 1932. The Garrat locomotive had all the defects which are inherent in articulated and tank locomotives. But the most important inconsistency in the idea of using this locomotive came from the fact that those in favor of the idea had forgotten, or perhaps did not even know, the circumstances which had led to such a complicated arrangement of indispensable components of the locomotive of the Garrat type. It is a known fact that the increase of grate area requires placing it not only above the frame of the locomotive but also above the wheels, which is possible only if the axis of the boiler is considerably raised. Given the impossibility of placing the boiler in this position under the standard low clearances and the low structure of locomotives the installation of a wide firebox required the removal from under it of the driving wheels, which were grouped into two individual trucks carrying the weight of the ends of the main structure of the locomotive. It follows that the Garrat locomotive can be justified only under conditions of standard low clearances and low structure of locomotives. In the USSR, as it is known, standard clearances and the structure are the highest in the world, and therefore the basic idea of the Garrat locomotive was not compatible with the conditions under which it was tried.

The second failure occurred in the building of the 2-7-2 AA locomotive. This locomotive was designed and built on the basis of a wrong idea of the forthcoming development of the national economy of the country. With the weight on drivers of 140 tons and with the rating of 5000 horse power the basic requirements of the traffic of the country could not be satisfied. The idea of seven driving pairs was supposed to be an answer to articulated locomotives. The design was also most unsuccessful. Three consecutive pairs of flangeless wheels caused frequent derailments. The weight on drivers was not fully utilized, the work of the coupling rods was unsatisfactory. In spite of the fact that the locomotive was equipped with two coal stokers steam generation was unsatisfactory.

4. 0-4-0 o^d and O^v LOCOMOTIVES

The first locomotives of the 0-4-0 type in the world were built in Russia at the Aleksandrovskiy Plant in 1858.

By the '90's of the last century the most widely used freight locomotives of the Russian railway system were of the 0-3-0 type. But in the '80's of the last century the need for more powerful locomotives had already come to a head. By that time there existed several Russian types of 0-4-0 types, which were built on designs of Kolomna, Nevskiy, and Maltsevskiy plants. Most of these locomotives had engines of single expansion.

For the South- Western railroads and for the Vladikavkaz railroad, which then were in the hands of private companies, 0-4-0 locomotives were built with compound engines. Their designs were worked out by L.M. Levi for the South-Western railroads and by V.I. Lopushinsky for the Vladikavkaz railroad. The first had a corrugated firebox and an outside steam distributing mechanism of unusual type while the second design had the usual firebox and a radial-pendulum type of steam distribution mechanism. The Ministry of Communications ordering locomotives for the State-owned railways at first selected 0-4-0 locomotives with single expansion engines built on the design of the Kolomna Plant. In 1892, because the principle of compounding was considered to be a progressive one and justified by practical experience in the work with saturated steam, the question was raised within the Ministry about ordering for the State-owned railways of 0-4-0 locomotives with compound engines. The 0-4-0 type locomotive of the Vladikavkaz railroad was taken as a model.

After it has undergone several changes this locomotive became a normal type for the 1893 0^d series of Russian State-owned railroads. By 1 January 1895, 466 0^d locomotives had already been built. However, in steam and fuel consumption these locomotives could not be considered satisfactory.

The question of their improvement was considered at the Seventeenth Advisory Congress of Engineers of Railroad Locomotive Departments in 1896 and after this the project of redesigning was turned over to the Kolomna Plant. On the initiative of the director of the plant, Gleb-Koshanskiy, certain changes in the locomotive were made, the most important of which were the introduction of difference in admissions of steam in the two cylinders, the increase of the wheel diameter to 1200 millimeters, and the raising of steam pressure to 11.5 absolute atmospheres (later to 12).

The introduction of the principle of different admissions of steam, i.e., of greater volume in the left cylinder of low pressure and of lesser volume in the right cylinder, was the result of the classic experiments of A.P. Borodin in the steam locomotive laboratory built by him in 1880. This work was published by him in 1886. As a result a standard and an improved 1897 type (series 0^d) was produced. This locomotive found considerable use on the Russian railway system (Figure 1).

In 1901 under the presidency of N.L. Shchukin there was established a commission on the eradication of defects of the standard freight steam locomotive. This commission was composed of representatives from the Engineering Advisory Board, from the Technical Department of theAdministration of State-owned railroads, from the Locomotive Department, and of engineers of locomotive-building and car-building plants.

Subsequently this commission was called The Commission on Rolling Stock and Locomotives and it worked under the permanent chairmanship of N.L. Shchukin from 1901 to 1917.

A considerably improved standard freight locomotive of 1901 type (series 0^v) was built from 1901 to 1908 and became the most widely used in prerevolutionary Russia. The most important improvement was in the replacement of the radial-pendulum steam distributing mechanism with the link-pendulum mechanism, which is now used exclusively everywhere.

Locomotives of the 0^v type are in service even now, being used as switchers (Figure 2).

From 1898 to 1900 0 locomotives underwent a test study on the Kharkov-Mikolaevsk RR (which later became a part of the Southern Railroad). The tests were continued in 1908 on the Ekaterininskiy Railroad and in 1909 on the Tashkent Railroad. The elaboration of the results of the first tests with 0^d locomotives was completed in 1906, that is, five years after the construction of 0^v locomotives was begun. Therefore, the results of the tests could be used only for the determination of tractive force of the locomotives and they did not influence the design. By that time production of 0^v locomotives was coming to an end. The initial exploitation of locomotives of standard type was not sufficiently satisfactory to prevent temporary doubts as to the value of the principle of compounding. As an experiment, in 1896 on the Khar'kov-Nikolaevsk Railroad and in 1897 on the Ryazan'-Ural Railroad, two 0^d locomotives were converted to the single expansion type.

The results were unfavorable and both locomotives were reconverted to compound engines. They were not subjected to any test study.

In 1913 one locomotive was specially reconverted to single expansion for tests which made it possible to judge as to the advantages of compounding with the use of saturated steam. Somewhat earlier, in 1907-1908, on the Nikolaevskiy Railroad 13 locomotives were equipped with superheaters of different designs and with single expansion engines (series OP). Tests, conducted in 1911-1912 with one of these locomotives, demonstrated that under freight conditions, and especially on roads with long grades, the change-over to single expansion with superheating is advantageous not only in superheating per se, but also in the return to the symmetrical design of the engine, which presented an opportunity to pull longer trains with the same weight of engine on the drivers, and to improve, especially at low speeds, the efficiency of the boiler.

In 1929-1930 there appeared two other types of 0^v locomotives which were the results of modernization of the latter. In one type a superheater was installed while the compound engine was retained (series 0^{n}). In the other type new boilers with pressure of 14 absolute atmospheres were installed (series 0^u). Neither of the two types found widespread use, because 0-4-0 locomotives were gradually

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removed from passenger and freight service, and their conversion to modern types necessitated expenses not justified in switching service.

Characteristics of O^d, O^v and of other locomotives are given in Table 6.

See Table 6 on following page

5. 1-4-0 Ts, Sh, Shch, AND R LOCOMOTIVES

The first locomotive of 1-4-0 type in Russia was built in 18[illegible] according to the design of V.I. Lopushinskiy for the Valdikavkaz Railroad and was identified as series Ts (Figure 3). At the very end of the last century construction of the Chinese-Eastern Railroad was begun. At the time both of these railroads had a common purchasing department for rolling stock. Because of this Ts series locomotives were built simultaneously for both roads. One of the Ts locomotives was exhibited at the Paris World Exhibition in 1900. These locomotives turned out to be satisfactory, but soon they were incompatible with the increased weight of trains. More powerful locomotives were needed, and V.I. Lopushinskiy was commissioned to redesign them along the lines of the same 1-4-0 type. The detailed elaboration of the design and the building of the locomotives was

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TABLE 6

CHARACTERISTICS OF 0-4-0 O^d, O^v and OF OTHER LOCOMOTIVES

Series	Cylinders, diameter in millimeters Pressure High	Low	Stroke in Millimeters	Drivers diameter in mm	Pressure in Absolute Atmospheres	Evaporating Heating Surface in Square Meters	Grate Area in Square Meters	Weight in Tons On Drivers	In working order
O^d	530	730	650	1150	11	167	1.9	51	51
O^d	530	730	650	1200	11.5	153	1.9	51	51
O^v	530	730	650	1200	12	153	1.9	51	51
O^p	500	---	650	1200	12	127	1.9	52	52
O^{ch}	500	730	650	1200	12	132	1.9	53	53
O^u	530	730	650	1200	14	153	1.9	54	54

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carried out by the Bryansk Plant.

The first S locomotives were built in 1902. Actually they turned out to be heavier than required by the design and they had some defects in design, which limited their use to these two railroads. The piston valves worked unsatisfactorily and often the cylinder mountings were weakened (Figure 4). A very small number of locomotives of this type were also experimented with on the Yekaterinskiy Railroad.

An original feature of S^h locomotives was the construction of cylinders which were cast together with a half of the frame mounting and of the support for smoke box, together composing that massive cylinder block which is now used in all locomotives having a plate or girder frame. This was the only case in Russia, and a very rare case in world experience, when block cylinders were used on a sheet frame. The engine was axial with the cylinder incline of 1/30. Sliding valve shafts were placed inside, and the linkage from the outside steam distributing mechanism to the cylinder valve was effected by means of a lever with two shoulders, also serving as an accelerator. These locomotives had many of the most important parts interchangeable with those of the passenger 2-3-0 G locomotives built by the Bryansk Plant for the same railroads. (Figure 53). Boilers, cylinders, and parts of the steam distribution mechanism were interchangeable in these locomotives.

Further increase in the weight of freight trains of State-owned railroads called for the use of more powerful locomotives. N. L. Shchukin, then at the head of locomotive building, was, as mentioned above, in favor of the use of front trucks in locomotives. The correctness of this point of view was subsequently

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fully confirmed. Not only did trains have to be longer, but also speed had to be increased. The Commission on Rolling Stock and Locomotives decided on a freight 1-4-0 locomotive. This choice at the time was absolutely correct, because at the time, as yet, there was no well defined need of locomotives with five pairs of coupled wheels. The most powerful of the 1-4-0 locomotives at the time was the S^h series locomotive, which, however, for reasons already mentioned, was not considered by the Ministry of Communications as satisfactory for mass production. According to the decisions of the Commission the S locomotive was accepted only as an initial model in which several modifications in design and improvements had to be made. The work of redesigning was given to the Kharkov Plant, whose Bureau of Design at the time was headed by A. S. Rayevskiy.

It was under A. S. Rayevskiy's guidance that the conversion of the S locomotive into the Shch was accomplished. Block cylinders were replaced by separate cylinders and piston valves by sliding valves.

After the Shch locomotives were built by the plant, they turned out to be heavier than planned. The load from a pair of driving wheels upon the rails reached 17 tons instead of the planned 15 tons. Furthermore, after the elimination of defects in design, inherent in the Sh series, new defects would appeared. Passage of locomotives on curves was not quite satisfactory and the wheels had a tendency to slip. With the subsequent introduction of modifications in design the locomotives were somewhat improved and made lighter, but a reduced load from a pair of driving wheels upon the rails to less than 16.5 tons could not

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be achieved. The locomotives had to be put into service on roads with rails and bridges of which were not reinforced and which were designed for a 15 ton load.

The experience of exceeding allowable loads indicated that the limits set at the time were too low, since no detrimental effects were observed. This was an indication of the positive value of the experience with these locomotives. In 1908 and 1909 Shch locomotives underwent a series of tests on the Yekaterininskiy Railroad.

In 1910 several Shch locomotives with single expansion engines and superheaters ($Shch^p$ series, (Figure 6) were built by the Bryansk and the Sormovo plants for the Moscow-Kieyv-Voronezh Railroad and for the Yekaterininskiy Railroad. In 1911 two of these locomotives were tested on the Nikolayevskiy Railroad. The locomotives had somewhat too large cylinders and superheating was somewhat low (250 to 280 degrees). Return cranks remained too far foward. With the inside admission of steam into cylinders, this necessitated during the forward stroke the holding of the link block at the top of the link, because of which the play of the block was quite considerable. Large dimensions of cylinders and the tendency of wheels to slip were shortcomings of the $Shch^p$ locomotives.

In 1912-1914 there existed on Russian railroads locomotives with compound engines and with superheaters (N^{ch}, U^u, Y^{ch}). A fairly economical operation of these locomotives under low speeds demonstrated that under certain conditions combining compound engines with superheating might prove useful. As experience has shown, (tests of 1912-1914 on the Nikolaevskiy Railrcad, 1925,

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pages 355, 389, 415), compounding together with superheating cuts down the loss of steam heat through the cylinder walls, because compounding decreases the range of temperature fluctuation in each cylinder. Furthermore, leakage of steam through cylinders and valves is also decreased. This was the reason that led to an attempt to use the same combination in the Shch locomotive. The installation of superheaters on Shch locomotives, while compound engines were retained, was turned over to the Putilovskiy Plant. The Locomotive-Technical Office was headed by A. S. Rayevskiy, who was the author of the original design of the Shch locomotive.

Parallel with the work carried out at the Putilovskiy Plant, the Khar'kov Plant in the person of B. I. Karchevskiy was also working on the improvement of the Shch locomotive. The basic feature of the design was maximum interchangeability of parts of the Shch^{ch} locomotive and of the standard series of Shch locomotives. The specifications also stated that reconversion of already existing Sh locomotives into Shch locomotives could be carried out with the same designs both by the locomotive-building plants and by railroad locomotive repair shops.

Of the two designs submitted by the two plants the Commission on Rolling Stock and Locomotives approved the one submitted by the Putilovskiy Plant. In 1914 the plant received a trial order for nine locomotives, but the World War, which started about that time, interfered with the building of these locomotives and the first one was built only as late as 1921. Working under the same set of conditions as Sh locomotives, the Shch^{ch} locomotives proved to be much more economical in fuel consumption. Practical tests of one Shch^{ch} locomotive were conducted in 1927 on the October

Railroad under the direction of R. P. Grinenko.

The tests demonstrated the great efficiency of $Shch^{ch}$ locomotives, which should be ascribed to properly selected dimensions of cylinders and of boiler heating surface.

Comparison of $Shch^{p}$ and $Shch^{ch}$ locomotives indicated that in steam consumption the latter were 20 to 30 percent more economical than the first. However, it would be a mistake to ascribe such a considerable superiority of the $Shch^{ch}$ exclusively to the combined use of compounding and superheating. And it would be even a greater mistake to draw a general conclusion from this. The truth of the matter is that the $Shch^{p}$ locomotive was designed less successfully than the $Shch^{ch}$ locomotive.

Shch locomotives are often called Shchukin's locomotives. However, the role of N. L. Shchukin in the creation of this type of locomotive consisted only in his ascertaining that the 1-4-0 type itself was the most acceptable for Russian railroads, at the beginning of the current century, and also in his efforts on behalf [of] the use of this type by Russian railroads. But the design of the locomotive itself was made at the Khar'kov Plant.

Therefore, the popular idea that Shch locomotives were designed by N. L. Shchukin is not correct historically. The letter Shch, with which this series of locomotives was identified, greatly contributed to this erroneous idea.

On the initiative of the Candidates of Technical Sciences A. K. Yevtushenko and I. V. Pirin, one of the Shch locomotives was redesigned in 1947 and it received the identification as $Shch^{r}$

series (Figure 7). The firebox in this locomotive is located over the frame and is widened over the drivers and the cylinders have straight channels. Return cranks are modified because of the use of inside admission of steam. This locomotive was sent to Leningrad, and is now in service on the Leningrad Railroad.

1-4-0 R locomotives had tandem compound engines without superheating (Figure 8). Such an engine is symmetrical; it has four cylinders -- two on each side. The front are high pressure cylinders and the rear are low pressure. The pistons of both cylinders are mounted on a common shaft. Steam distribution is internal eccentric with a rectangular link. The locomotives were designed in 1898 by L. M. Levi for the Moscow-Vindava-Rybinsk Railroad. At first these locomotives were built by the Bryansk, Koloma, and Putilovskiy plants. Some were built abroad. R. locomotives were also used by the Moscow-Kiyev-Voronezh, South-Eastern, and Ryazan'-Ural railroads. For the last three roads R locomotives were also built by the Sormovo Plant.

These locomotives were built until 1910. Test studies of them were conducted on the Moscow-Vindava-Rybinsk Railroad under the direction of A. O. Chechott. With the weight on a pair of drivers of only 13 tons R locomotives were just about as good in their tractive force as Shch locomotives which had the weight on a pair of 16.5 ton drivers. But R locomotives were not as fast as the Shch locomotives. Their economy in fuel consumption was average. From the standpoint of maintenance and repair the tandem compound engine is inconvenient and mounting two pistons on one shaft resulted in wavy motion. Passage of R locomotive on curves was satisfactory, the load from the front wheel trucks was only 8 tons, i. e. it was favorable for the upper part of the roadbed.

Besides the locomotives of 1-4-0 type already discussed, there was a certain number of 1-4-0 locomotives of Kh series in service on the Moscow-Vindava-Rybinsk, the Vladikavkaz, and the Chinese-Eastern railroad. They were built abroad in 1898. This locomotives had a compound engine with four cylinders -- two on each side; the low pressure cylinders were mounted over the high pressure cylinders. Both piston rods acted on one eccentric.

On the Vladikavkaz Railroad Kh locomotives were converted to a single expansion engine with superheating; they were identified as Kh^P series. The inside steam distribution eccentric mechanism was replaced with link-pendulum.

Characteristics of 1-4-0 locomotives are given in table 7.

[See Table 7 on next page]

6. 0-4-0 V, AND V^S LOCOMOTIVES

[V in the above designation and following appears as a Roman letter in the original text.]

Locomotives of this type in 1908-1910 were called "a protest" on the part of the private railroads against the Shch locomotives which were in service on the State-owned roads. The opinion of private railroads was summed up as follows: "...the steam distribution system of the Shch locomotive is built on the idea of small inlet ports and high speeds. This condition, together with a large boiler and the front truck, made the Shch locomotive more adaptable to mixed service and even passenger service, but

TABLE 7

Characteristics of 1-4-0 Ts, Sh. Shch, and R Locomotives

Series	Cylinders Diameter in mm: High pressurs	Cylinders Diameter in mm: Low pressure	Stroke in mm	Drivers diameter in mm	Pressure in Absolute atmospheres	Heating Surface in Square Meters: Evaporating	Heating Surface in Square Meters: Superheating	Grate Area in m^2	Weight in Tons: On drivers	Weight in Tons: In Working Order
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Ts	530	750	650	1250	12	180	-	2.5	52	62.7
Sh	510	765	700	1300	13	199	-	2.8	61	75.3
Shch	510	765	700	1300	14	206	-	2.8	65	77.2
$Shch^p$	590	-	700	1230	12	169	43	2.8	64	77.3
$Shch^{ch}$	540	765	700	1300	14	177	51	2.8	65	78.2
$Shch^r$	575	-	700	1320	14	148.3	72.5	4.46	67	80.0
R	2x400	2x600	600	1270	12	180	-	2.5	52	60.8
Kh	2x343	2x584	660	1270	12	181	-	2.4	52	60.0

not for heavy freight service. This was realized by the majority of private railroads which ordered Shch locomotives reluctantly, despite the strong encouragement given them by the Ministry of Communications in the person of N. L. Shchukin. These railroads had the following point of view: the Shch locomotive is more powerful than the O not because it is of 1-4-0 type, but because its load upon a pair of drivers is larger; if we set the same load on the 0-4-0 type, we would produce a heavy freight locomotive more economical than the Shch type." (Tests of 1912-1914 on the Nikolayovskiy R R, Volume 1, 1925, page 8.) As can be seen, this opinion, contrary to N. L. Shchukin's opinion, encouraged private railroads to build slow locomotives and it increased the diversity in types of locomotives. But the principal opposition to the Shcch locomotive was because of its defects in design and its somewhat excessive weight.

0-4-0 V and Y locomotives so far as the design was concerned were more successful (Figure 9 and 10).

The V locomotive was designed by Ye. Ye. Nol'tein for the Moscow-Kazan'Railroad, and the Y locomotives were designed by the K. N. Baydak and N. P. Kas'yanov for the Armavir-Tuapse Railroad. The details of the designs of both locomotives were worked out by the Kolomna Plant. The load from a pair of drivers of the V locomotive was up to 16.5 tons, and of the Y locomotives, up to 15 tons. The first V locomotives were built in 1908, they were equipped with single expansion engines and superheaters. The front wheel pair had a displacement of 12 millimeters on each side and was equipped with a spring centering mechanism. To decrease the effect of side play, the tender was equipped with guides which grasped the rear part of the locomotive frame by means of helical springs. The locomotives were not economical in fuel consumption and they were noted for their rolling in motion. Because of these defects they were not used by other railroads.

As an experiment one of these locomotives had a direct flow engine with valve stream distribution. This was the first case in the world's practice of the use of direct flow engine in a locomotive.

The first Y locomotives, numbering 16, were ordered from the Kolomna Plant in 1910. They had two cylinder compound engines without superheating. Like the V locomotives, their first wheel pair had a side displacement and the tender was equipped with guides.

In 1911 when the second order for these locomotives was placed with the Kolomna Plant, the Armavir-Tuapse Railroad, at the initiative of A. O. Chechott, suggested that the plant equip the locomotives with superheaters while retaining the compound engine. The locomotives, received by the road in 1912, were identified as Y^{ch} series. Practice testing of the Y^{ch} locomotive was carried out on the Nikolayevskiy Railroad. These locomotives gave a record low specific consumption of steam, i. e. they were exceptionally economical. The low pressure cylinder had a diameter of 790 millimeters. So far it is the largest diameter ever used on Russian locomotives. It almost reached the limit of permisseable clearance, legally established for all railroad equipment, and this fact hindered further development of two cylinder locomotives with compound engines. Furthermore, balancing the engine with such a big piston diameter became difficult. The efficiency of the exhaust pipe crank in two cylinder compound locomotives is lessened, distribution of crank force is even less and in addition, driving gear and steam distribution systems wear out unevenly on each side. The case of the Y^{ch} locomotive demonstrates that two cylinder compound locomotives have reached the maximum of their power (1000-1100 horse power) with the existing steam and cannot progress any further.

Besides Armavir-Tuapse Railroad other private railroads of the Urals and Siberia also ordered Y and Y^{ch} locomotives.

The Olonets Railroad, which was in the process of construction in 1913-1915, also decided to place an order with the Kolomna Plant for Y locomotives. On the initiative of engineer A. A. Zhdanko the railroad expressed a wish to have the locomotive equipped with a single expansion engine and with a superheater (Y^{p} series). One of the members of the Engineering Board of the Ministry of Communications expressed his opposition to the suggestion of the railroad. He was of the opinion that the conversion of the Y^{ch} locomotive to single expansion would only ruin the locomotive. However, the railroad received the support of N. E. Shchukin. This decided the fate of Y^{p} locomotives, 14 of which were built in 1914-1915, that is, in the very beginning of the First World War (Figure 11). Their tractive and thermo-technical features were not fully ascertained, since no tests were made with the locomotives. In itself, the departure from an asymmetrical engine with its less satisfactory starting characteristics, the uneven work of its two cylinders, while producing a well-designed single expansion engine, was, of course, a step forward, not back. In connection with this, reference to $Shch^{p}$ and $Shch^{ch}$ locomotives

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was not justified, for the reasons already mentioned.

In the period from 1913 to 1915 inclusive, the Kolomna Plant built 64 Y^u locomotives for the Altai Railroad. They were the last and the most powerful of the Y series. These locomotives had a compound engine workiong on saturated steam. The general appearance of the locomotive is shown in Figure 12. In 1914, just before the war, the Warsaw-Vienna railroad placed an order with the Sormovo Plant for 0-4-0 locomotives (V^s series). Because of the urgency of the order, the plant used ready dies and a large number of parts from the passenger 1-3-1 locomotive which was being produced at the time in the process of building the locomotive. All-forged boiler plating was used, as a result of which boilers of V^s and S locomotives are identical in cross section and differ only in length. The firebox was shortened 285 millimeters, the length between the grates 700 millimeters, and the length of the smokebox 210 millimeters. Many other parts of the S locomotive were also used. V^s locomotives were the most powerful of the 0-4-0 type and their design was very good. Unfortunately, their tractive and thermo-technical characteristics remained unascertained.

In 1928-1929 V^s locomotives were built by the Bryansk Plant for industrial transport. They were identified as V^b and V^n series (Figure 13). V^n locomotives were produced without superheaters. On all V^b and V^n locomotives built by the Bryansk Plant water cleaners were installed.

Characteristics of V and Y locomotives are given in Table 8.

Table 8

CHARACTERISTICS OF 0-4-0 Y AND V LOCOMOTIVES

Series	Cylinder diameter in mm		Stroke in mm	Driver diameter in mm	Pressure in absolute atmospheres	Boiler heating surface in square meters		Grate area in square meters	Weight in tons	
	High pressure	Low pressure				Evaporating	Superheating		On drivers	In working order
(V)	540	--	650	1,300	12	163	36	3.2	64	64
Y	520	750	650	1,200	12	185	--	2.6	60	60
Y^{ch}	550	790	650	1,200	12	147	43	2.6	61	61
Y^{p}	550	--	650	1,200	12	147	43	2.6	60.5	60.5
Y^{u}	520	770	650	1,200	13	205.7	--	3.23	63.2	63.2
$(V)^{s}$	575	--	650	1,300	12.5	176	45	3.33	64.2	64.2
$(V)^{b}$	575	--	650	1,300	13	176	45	3.33	65	65
$(V)^{n}$	575	--	650	1,300	13	206	--	3.33	65	65

( ) mean that latin alphabet letters were used.

7. 0-5- 0 E LOCOMOTIVES

By 1911-1912 locomotives with four coupled wheel pairs were already inadequate for the increased weight of trains, especially on lines with long grades.

Linked locomotives with six coupled wheel pairs, which were in service at the time on the Moscow-Kazan' Railroad and on the Siberian Railroad did not come into wide use for reasons given later. On the Trans-Caucasian Railroad two American built 1-5-0 locomotives have already been in service for fifteen years. With their long rigid frame these locomotives, because of the loss of adhesion on the curves caused by slippage, could not make full use of their tractive power.

The first design of the 0-5-0 locomotive prepared by V.I. Lopushinskiy of the Vladikavkaz Railroad was submitted to the Commission on Rolling Stock and Locomotives as far back as 1909. The design called for a two-cylinder, single-expansion engine with the fourth pair of wheels the driving pair. The boiler was equipped with super-heater, and its axis was located 2,890 millimeters above the rails. To facilitate passing the locomotive on curves, its design tentatively provided for side-play of the first, third and fifth pair of wheels. The design, approved by the Commission in principle, was turned over to the Lugansk Plant for detailed elaboration.

Simultaneously with the submittal of the design by the Vladikavkaz Railroad, a similar design of 0-5-0 locomotives was being worked out by two other roads: the Moscow-Kazan' Railroad, and the Ryazan'-Ural Road. The Commission aptly called the attention of the Vladikavkaz Railroad to the necessity of correlating its design

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with the similar design by the other two roads.

In elaborating the design, the Lugansk Plant introduced the following changes: to obtain greater depth of the firebox the axis was raised to 3,100 millimeters; the third wheel pair was made the driving pair, which simplified the design of the engine; to give greater flexibility to the running gear the side play of the connecting rod bearings was increased two millimeters over the side play of the axel bearings. Moreover, the connecting rod bearings except for the bearings of the drive wheels were made without wedges, in the form of whole bronze bushings.

Such an arrangement not only simplified the design and accessibility of the parts for repair purposes, but it also allowed free sliding of bearings on the crankpins by obviating any possibility of interfering with the free side movement of the wheel pairs through inapt adjusting of bearing wedges. Originally, it was supposed to provide the first and the fifth wheel pairs with side movement.

Comparing the proposed design with the design of the ShchP locomotive boiler the Commission on Rolling Stock and Locomotives noted the absence of any substantial advantages in the new design. Because of it, the Lugansk Plant decided to increase considerably the dimensions of the boiler and fire grate.

According to calculations of Engineer V. I. Lopushinskiy, the most advantageous connection both dynamically and statically, was the combination of the second and the fifth wheel pairs, with the locomotive being guided by the first wheel pair operating on a large arm. Such an original combination, excelling all other

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principles, was first proposed by a Russian engineer. V. I. Lopushinskiy's principle was approved by the Commission. It is a known fact that it was fully justified by subsequent experience and it was applied to all series E locomotives.

The Ryazan'-Ural Railroad requested that a number of other modifications be made in the design of Lugansk Plant, the most essential of which were the use of the valve throttle, sliding valves with a split ring and separable discs, installation of a swinging part of the fire grate, and finally, the use of steel staybolts and of tubes without end sleeves.

The Commission on Rolling Stock and Locomotives made several other changes beforegranting final approval to the unified design of the Vladikavkaz and the Ryazan'-Ural railroads.

The thickness of tires was increased from 65 to 75 millimeters. As a result, the diameter of the wheels was increased from 1,300 to 1,320 millimeters. The thickness of the firebox walls was reduced to lessen the total weight of the locomotive. The diameter of cylinders was increased to 600 millimeters from 590 as provided in the original design. In this form the design of the Lugansk Plant was given final approval. The design was identified as E series.

The first E locomotives (figure 14), built in 1912, fully substantiated the soundness of V. I. Lopushinskiy's principle, which was approved by the Commission and which concerned introduction of side play for the second and the fifth wheel pairs. With the third flangeless driving pair completely free and adequately smooth passage of the locomotive on curves of up to a 150 meter radius was assured. Further experience also demonstrated that because of the friction of bearings against the journals of the axles and because of the action of springs, moveable wheel pairs, especially the fifth, helped to keep the locomotive from weaving in spite of their side play caused by the rails on curves.

Such detailed consideration of the E locomotive design by the Commission the Rolling Stock and Locomotives contributed to the fact that this turned out to be one of the best Russian locomotives. The original design, submitted by the Vladikavkaz Railroad, had not had sufficient thought, and the capacity, as envisioned by the design, was considerably smaller. The prolonged consideration period served as an excuse for individual specialists to attack the Commission. Perverting facts, they charged the Commission with opposition to the 0-5-0 type of locomotive. Unfortunately their clamor found response also in the Soviet press, where it was admitted without proper criticism.

A clear cut instance of it is represented by a short historical review of the development of the 0-5-0 type of locomotive which served as an introduction to the album of detailed drawings of the 0-5-0 E^m locomotive published by the Editorial Bureau of the Glavlocomotive in 1936, in that part of the review which deals with the facts of the prerevolutionary period. This part of the article is nothing but pure recounting of what was said in Lomonosov's monograph on E, E^v, and E^{sh} locomotives.

The author of the article, not seeing those tremendous changes which took place in the country after the victory of the Socialist Revolution, compares the three year period between the conception of the idea of the 0-5-0 locomotive and the building of the locomotive in prerevolutionary Russia, with the six month period which was required for building the FD locomotive in the Soviet era. In this short period, the superiority of advanced methods of Soviet production over backward methods of capitalist production of Tsarist Russia was manifested.

However the author of the article, reiterating the same monograph, charges N. L. Shchukin with being guilty of procrastination in the design and construction of the 0-5-0 type.

In 1913 E locomotives were also ordered for the North-Donets Railroad as well as for the Vladikavkaz and Rayzan'-Ural Railroads on the initiative of Ye. I. Mokrshitskiy the question was raised of enlarging the cylinders. This question was considered several times by the Shchukin's Commission by whose decision, dated 30 August 1913, the cylinder diameter was increased to 630 millimeters. In addition to this, the railroad suggested several small changes in design which were accepted by the Commission.

The E locomotive with the cylinder diameter of 630 millimeters was tested on the North-Donets railroad in 1915. On 13 August 1914, by a decision of the Engineering Board of the Ministry of Communications, E locomotives were put in production also for the State owned railroad network. On 20 September 1914 the Commission on Rolling Stock and Locomotives decided to increase the cylinder diameter to 650 millimeters. Such cylinders were used on all subsequent E locomotives of all series, including the last one, the E^r series which is in production now and also on the SO locomotives the engine of which is identical with the engines of E^m and E^r locomotives.

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Together with the increase to 650 millimeters of the cylinder diameter in locomotives of 1915 type, the boiler and the fire grate were somewhat increased from 4.2 to 4.46 square meters. The heating surface of the superheater decreased because of the installation of twenty five flues instead of 27 which were used on E locomotives of 1912 and 1913 types.

In 1914 the Engineering Board approved still another design of 0-5-0 type locomotive, series E, which was prepared by the Ryazan'-Ural Railroad in collaboration with the Putilovskiy Plant. The design called for a four-cylinder, compound engine with a crankshaft and an engine operating on superheated steam.

During the First World War the Putilovskiy Plant started building the locomotives, and brass fireboxes and moulds for castings were made.

The events of 1917 put a stop to construction of E locomotives, and their construction was never resumed. In itself, the 0-5-0 type with its complex four-cylinder engine could hardly have any advantages over the E locomotive.

During the first years after the October Revolution, railroad transport greatly needed considerable numbers of new locomotives. The existing inventory of locomotives was in a greatly worn condition and needed overhauling. All industrial and transport plants and railroad shops were drafted for the task of overhauling the inventory. Building of new locomotives could not be organized at once. Consequently the locomotive inventory was replenished by importation from Sweden (E^{sh} locomotives) and from Germany (E^{g} locomotives).

The locomotives ordered in these countries were built on Russian blueprints and were actually E locomotives of 1915 type (figure 15). Thus, the successfully implemented design of E locomotives was conducive to their further distribution in the postrevolutionary period during which most of these locomotives were built. These locomotives differed from the basic 1915 type only in small parts. Their initial service on the USSR railroad network commenced in 1921-1923.

Upon demand of the Soviet Government the parts of these locomotives were made interchangeable and they were made with established tolerances. As an experiment two locomotives had direct flow engines with sliding-valve distribution and ejection-exhaust system in which the ejection of steam from one cylinder lowered the pressure at the ejection of steam from the other cylinder.

This system was not developed any further.

Considerable operational experience in the use of locomotive superheaters, a quantity of data obtained as a result of experimental research to which were subjected almost all types of Russian locomotives, and, finally, the first classic works on the locomotive thermal process by the distinguished Soviet scientist, at present an Academician, S. P. Syromyatnikov, made it possible to determine that the dimensions of the superheaters which were used on the locomotives were not sufficient and that they had to be considerably increased. Toward the beginning of development of Soviet locomotive building, firmly established by 1923, the question of the use of superheaters of greater capacity came to the fore and technically was well worked out. With the building of the first Soviet locomotives these more powerful superheaters came into practical use.

Improvement of superheaters should have been, but was not accomplished in E^{sh} and E^{r} locomotives, which was a mistake as A.S. Rayevskiy justly pointed out.

Increase in the capacity of superheaters progressed both by means of increasing the number of pipes and by improving them. Instead of four-flue, two-cycle pipes six-flue, two-cycle pipes of Chusov's design began to be introduced. Their advantage was in increasing of heating surface and in more completely utilizing the heat of the gaseous flow in the flues. Moreover, these pipes reduced resistance to the passage of steam from boiler to engine. Fine pipes used in these flues (24 x 18 millimeters), advantageous from the standpoint of increasing superheating, turned out to be unsatisfactory in operation, because they warped considerably. Because of this further installation of Chusov pipes was discontinued, and later there began a gradual return to the old tested four-flue units with a pipe diameter of 33 x 27 millimeters.

The second improvement in the locomotives, used en masse both in the newly built locomotives and on the ones already in service, was the waterheater. The combination of both of these thermotechnical improvements which raised both power rating and economic efficiency, was first of all accomplished on E locomotives, the mass production of which began in 1926. These locomotives were identified as the E^{u} series. In addition, water cleaners were installed on these locomotives in supplementary feeding domes, where feed water was produced.

The project of redesigning the E locomotive into the E^u (figure 16) was worked out at the Profintern Plant (formerly Bryansk Plant).

In 1931, at the Institute of Improved Traction Design which now is a component of the Central Scientific Research Institute of Railroad Transport, the matter of increasing tractive force of an engine by means of increasing steam pressure from 12 to 14 absolute atmospheres was considered. The boiler was tested for stress and it was established that it was entirely feasible to raise the pressure by 2 absolute atmospheres without increasing the wall thickness, or reinforcing the stays. However, the driving gear already carried rather high stress, because when the diameter of the cylinder was raised from 600 to 650 millimeters, the driving gear was not reinforced. With the change over to 14 atmospheres it was necessary to reinforce the cam with the guide, the cam shaft, the piston rod, the main rod, coupling rods and the driving pin. In addition, the ends of the main rod and of the coupling or side rods along the oiler sections were reinforced because breaks in this section had been experienced.

Because of the increase in the weight of the piston assembly, main rods and coupling rods, the whole balance of the locomotive had to be reexamined. With the increase in tractive force as a result of boiler modifications, the engine had to be given a better coefficient of adhesion. For this purpose the locomotive was equipped with a sand box of large capacity (900 kilograms) and an improved sander mechanism.

The E^u locomotive, the power rating of which was raised as stated above, was identified as the E^m (modernized) series (figure 17).

Water heaters, installed on E^u locomotives and also on locomotives of other series, operated highly unsatisfactorily, and as a result they were not installed on E^m locomotives. The feed dome and the water cleaner mounted on the third course of the tube part of the boiler of the E^u, were moved to the first course on boilers of the E^m series to protect the firebox from sharp changes in temperature which take place when water is fed into the boiler. In connection with this, the steam dome was moved from the first course to the second. Because of the decrease of diameters of courses towards the front grate, placement of the water cleaner trough in the first course required removal of six fire tubes from the boiler, three on each side. Thus, in place of the 157 tubes installed in the boiler of E^u locomotives, 151 tubes were used in the boilers of E^m locomotives. From 1933 until 1935 feed domes and water cleaners were not installed on E^m locomotives. Chusov elements were completely replaced by the four-flue, two-cycle elements.

1932 and 1933 -- the years of the Second Stalin Five-Year Plan were marked by the wide introduction of welding into locomotive building and especially into locomotive boiler making. The value of welding was not confined merely to simplification and to the lowering of construction and, in part, maintenance costs.

The principal advantage in welding is the lighter weight of welded assemblages in comparison with similar cast or riveted parts. However, no matter how advantageous the lessenging of weight might

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be in itself, i.e., an indication of a more complete and perfect use of metal, so far as the locomotive is concerned its lighter weight results in the reduction of tractive force, and, consequently, in the reduction of power. That is exactly what happened to E^m locomotives.

The weight on the drivers of these locomotives built before 1932 was 85.3 tons, and the weight on the drivers of locomotives built in 1933 was reduced to 78.1 tons. The loads transmitted from the wheel pairs ofthe latter locomotives to the rails are distributed approximately as follows: from the first pair -- 16.35 tons, the second -- 16.265 tons, the third -- 16.65 tons, the fourth -- 14.44 tons, and the fifth -- 14.39 tons. The reduction in the weight on the drivers and uneven distribution of loads on wheel pairs caused chronic wheel slipping. Raising steam pressure by 2 atmospheres gave more power only to the engine. As the tests conducted by the TsNII indicated, the efficiency of the E^m locomotive as compared to the E^u was somewhat though slightly lowered. The unsuccessful experience with the weight reduction of the E^m locomotive, still meant that a rational solution had to be found to the problem of giving the locomotive additional weight. This solution was proposed by a Candidate of Technical Sciences, I.V. Pirin. While the width of the fire box was left intact, the length was increased 539 millimeters, which in turn required lengthening the side frames 450 millimeters. This modification of locomotives already built was carried out by cutting the fire box between the second and the third row of stay bolts counting from the fire grate, and by subsequent welding into the firebox and the case of strips the width stated above. The frame was lengthened in the same

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manner. The increase in the dimensions of the firebox increased the weight of the locomotive on the drivers to 81 tons. The fire-box itself increased in volume from 7.4 to 8.7 cubic meters, in heating surface from 18.1 to 22.9 square meters, and in grate area — from 4.46 to 5.1 square meters. Lengthening the firebox increased the power rating of the boiler approximately 15 percent and the efficiency 8 percent.

E^m locomotives (figure 18) with lengthened the fire-box were identified as E^r (redesigned). During the Great Patriotic War a certain number of E^r locomotives, with boilers of S^u locomotives, were built.

In 1937-1941 a considerable number of E locomotives of different series were equipped with feed water heater in the tender, and a few locomotives had a gas air heater installed. However, the effectiveness of these two modern devices was only slight. The water heaters in the tender possessed some very vital defects, i.e., unsatisfactory operation at medium boiler settings, and complete cessation of functioning at low settings. Because of these defects they were removed.

Gas air heaters with horizontal pipes also were unsatisfactory because their pipes easily clogged. Besides, it was observed that they were not evenly exposed to cold air, with the result that their joints with the grate became loose.

In 1941 the Rostov locomotive repair shops produced an E^m locomotive with a superheater of increased capacity the pipes of which were located in 46 flues, a gas air heater with a surface of 58.7 square meters, and a water heater in the tender. In 1942-1943 this locomotive was tested on the Tomsk Railroad and it was found that it had 15-25 percent more power than the regular E^m locomotives, and its fuel consumption was 12-30 percent less.

Characteristics of E locomotives are given in table 9.

[Table 9 on the following page]

8. 0-3-0 + 0-3-0 Th LOCOMOTIVES

The first articulated, four-cylinder compound locomotives in Russia were used on a narrow-gauge Uroch-Vologda-Arkhangel'sk line of the Moscow-Yaroslavl-Arkhangel'sk Railroad in 1897 (the width of the guage -- 1,067 millimeters). This line passed through the tundra of the northern region and at that time could carry only light rolling stock.

The considerable weight of the trains for the narrow gauge line necessitated the use of fairly powerful locomotives. With a load limit of 8 tons from a pair of wheels on the rail, the use of six coupled pairs of wheels was dictated. To facilitate passing on curves, the wheels were divided into two independent groups; the first three pairs were mounted on the front turning truck, they had outside wheels; the last three pairs were mounted on a rigid frame and had inside wheels. These locomotives were built by the Putilovskiy Plant, but a certain number of them was built abroad. Low pressure cylinders were mounted on the front truck. Later, in 1915, the same line received 30 articulated locomotives of American construction, ordered in America on account of the war.

Table 9

CHARACTERISTICS OF 0-5-0 E LOCOMOTIVES

Series	Cylinder diameter in mm	Stroke in mm	Drivers diameter in mm	Pressure in absolute atmospheres	Boiler heating surface in square meters: Evaporating	Boiler heating surface in square meters: Superheating	Grate area	Weight in tons: On drivers	Weight in tons: In working order
E 1912	600	700	1,320	12	194	52	4.2	80	80
E 1913	630	700	1,320	12	194	52	4.2	80	80
E 1915	650	700	1,320	12	207	51	4.46	81	81
E^u	650	700	1,320	12	195	66	4.46	85	85
E^m 1931	650	700	1,320	14	193	66	4.46	85	85
E^m 1933	650	700	1,320	14	193	66	4.46	78	78
E^r	650	700	1,320	14	200	66	5.10	81	81
E	2x460 2x650	650	1,300	14	217	60	4.63	81.3	81.3

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Independently of this first experience with locomotives of this kind, in 1896 Ye. Ye. Nol'tein began designing a similar articulated locomotive for the Moscow-Kazan' Railroad (for regular gauge). The first such locomotives were built by the Bryans and the Putilovskiy Plants in 1898-1899. They were identified as Th series (figure 19). In 1903 they were also ordered by the Siberian Railroad. Besides the two above mentioned plants, the Kolomna Plant also built these locomotives. Tractive force of the first Th locomotive reached 14,000 kilograms, which exceeded the tractive force of the O^d locomotives by 60 percent and exceeded the strength of screw coupling by 40 percent. To combat this difficulty, upon the suggestion of Ye. Ye. Nol'tein, the first 15 cars were tied to the tender with steel cables, which extended on both sides of the cars and were attached to the cars by special hooks. The cables were tightened with a winch and this arrangement lessened the stress in the couplings of the first cars. The equal tightness of the cables on both sides was insured by a pneumatic device which used compressed air from the main brake tank. However, in practical operation, tightened cables were seldom used, and in 1911 this arrangement was abolished on orders of the Commission on Rolling Stock and Locomotives.

In fuel consumption the articulated locomotives turned out to be less economical than the ordinary ones. Th locomotives built in 1904 by the Putilovskiy Plant for the Moscow-Kazan Railroad were equipped with a weak superheater consisting of 15 two-cycle elements in four flues which dried rather than superheated the steam. Later the number of elements in the superheater was increased to 21 to give it greater capacity. This locomotive was identified as Th^{ch}

series (figure 20).

Despite the introduced improvements, the locomotives continued to consume too much fuel, which forced Ye. Ye. Nol'tein, in collaboration with Ye. G. Kestner, to conduct a thorough study of their operation. The test uncovered one of the reasons for excessive steam consumption. During one of the runs considerable wheel slipping of the front truck was observed. This led the observers to suspect that too much steam was being passed through the valves of the high pressure cylinders. Attention was turned to the design and construction of the valves. They were of the piston type and their packing ring was cut crosswise into three sections which were pressed to the bushing by the force of steam. The same kind of valves were used on the passenger 1-3-0 N^v and N^u locomotives and their operation was highly unsatisfactory. When such rings were replaced, on Th^{ch} locomotives, with split rings, the operation of the locomotive was markedly improved. Furthermore, a more advantageous ratio of the elements of high and low pressure steam distribution was employed. Examination of conditions under which the locomotive was operated revealed that high fuel consumption per unit of run was caused by too low weight of the train which was established by operative instructions for one direction of travel. Increase in the weight of the train together with the improvement in design stated above resulted in normal fuel consumption.

The railroad continued to order these locomotives for a number of years. In 1910-1911 they were given some additional power by the Bryansk Plant, and locomotives with this improvement were identified as Th^{ch}_b series (figure 21). They were still in production

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after the October Revolution and the Kolomna Plant built 55 locomotives from 1920-1924.

In 1916 the Th_b^{ch} locomotive underwent a series of tests which demonstrated that its specific steam consumption could be considered satisfactory for speeds only up to 20 kilometers per hour. Above this speed steam consumption greatly increased. As a result articulated locomotives with compound engines were known as ideal pushers.

In operation, Th^{ch} locomotives were not quite satisfactory in their passage on curves; there were cases when the front truck dislodged the rails and the tires. In the use of articulated locomotives with compound engines Russia was several years ahead of the United States of America, and built the first locomotives of this type only in 1903, by using Russian experience. In 1900 the Th locomotive was exhibited at the Paris World Fair. At the International Railroad Congress in Bern in 1910 the Th locomotive was acclaimed as an engineering triumph.

[Table 10 on the following page]

9. 1-5-0 YE AND F LOCOMOTIVES

The first locomotives of the 1-5-0 type appeared in Russia in 1895 on the Transcaucasian railroads. They were freight locomotives with four-cylinder compound engines. There were two cylinders on each side with the low pressure cylinder mounted above the high pressure cylinder. Both piston-valve rods acted on the same valve. Dimensions of the locomotive are given in table 11. Only two locomotives, as an experiment, were ordered abroad, and no more

Table 10

CHARACTERISTICS OF 0-3-0 0-3-0 Th LOCOMOTIVES

Series	Cylinder diameter in mm		Stroke in mm	Drivers diameter in mm	Pressure in atmospheres	Heating surface in square meters		Grate area	Weight in tons	
	High pressure	Low pressure				Evaporating	Superheating		On drivers	In working order
Th	2x475	2x710	650	1,220	12	187	--	2.5	81	81
Th^{ch}	2x510	2x710	650	1,220	12	174	39	3.5	89	89
Th^{ch}_{b}	2x510	2x770	650	1,230	12	178	47	3.4	89	89

locomotives of this type were built at this time.

20 years later, in 1915, during the First World War, mass building of the 1-5-0 Ye locomotives was begun. The basic characteristics of these locomotives were created by Russian engineers. The urgency of building and the preoccupation of Russian industry with war orders did not permit placing orders for the locomotives among Russian plants. The Ministry of Communications was forced to order these locomotives abroad.

This project was approved by N. L. Shchukin. Locomotives began to arrive in Russia in October 1915 and after being assembled in the main railroad shops of the Chinese-Eastern Railroad in Kharoin were sent to the Per'm, the Samara-Zlatoust, and the Yekaterininskiy railroads.

1-5-0 locomotives were identified as the Ye^f, Ye^c, and Ye^k series. The Ye^k had boilers identical with the Ye^f locomotive boilers, and their engines and running gear were those of the Ye^c locomotives (figure 22). In the initial operating period of these locomotives on Russian railroads there were some breakdowns due to the difficulties which arose because railroad personnel were not accustomed to dealing with locomotives of that particular design and construction. In spite of these complications, the 1-5-0 locomotives had acceptable tractive characteristics for freight service on Russian railroads. Due to this, in 1916, when the matter of a new large order for locomotives arose, the same 1-5-0 type was accepted.

By that time there was sufficient experience in operation of the first 1-5-0 Ye locomotives. On the basis of this experience, a list of desireable modifications in the design of locomotives was

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submitted to the Commission on Rolling Stock and Locomotives. The suggestions were considered in a number of meetings of the Commission, and on 8 August 1916 they were approved. Subsequent 1-5-0 locomotives (Ye^1 series) were built with the desired modifications of design. (figure 23).

In 1935, one of the Ye^f locomotives was equipped by the Dnepropetrovsk Plant with a I.V. Pirin chamber superheater. The essential feature of the I.V. Pirin superheater was that it was removed from the tube section of the boiler and placed into two long chambers mounted on the sides of the boiler. To enable the gases to pass from the firebox into the superheater two special openings were cut in the fire grate on the sides, below the tubes. Complete separation of the gasses into two independent streams permits control over them, i.e., superheating does not wholly depend upon boiler operation as in the case of a regular flue superheater and therefore it can be greatly increased. For this reason, the smokebox was divided into two separate chambers, each of which was equipped with its own system of smoke suction. The draft created by them is subject to control, and depends upon the volume of steam passing out. The axis of the boiler had to be raised from the height of 2,297 millimeters above the rail level to the record height of 3,600 millimeters, which represents the highest boiler mounting ever used in the world. Furthermore, the cylinders in these locomotives were changed; they had straight steam channels and a valve diameter of 375 millimeters. This locomotive was identified as the Ye^{pf} series. In tests superheating reached a temperature of 475 degrees. The power was increased by 50 percent and the economy of operation about 20-25 percent.

Installation of the I.V. Pirin superheater entails considerable remodeling of the locomotive, but the results of this remodeling are so beneficial, that this modification should be adopted by many other types of locomotives, at first as a trial for comparison with locomotives without this modification. According to observations the color of gases leaving the first chamber of the smokebox or the superheater is always lighter than the color of gases from the second chamber.

This condition was explained by the fact that in the superheater chambers there was complete combustion of hydrocarbons and coal dust. This also contributed to the economy feature of the locomotive. Boiler efficiency rose to 73 percent.

During the Great Patriotic War the Soviet locomotive inventory was able to successfully serve the Soviet Army because of the new forms of operation under war time conditions, creatively utilized by the Soviet railroad personnel, and because of the utmost use of internal assets (locomotive convoys of NKPS, Lunin's methods of locomotive maintenance and so forth). Under conditions of almost complete cessation of locomotive building there arose a problem of repair and production of locomotive spare parts, which was successfully solved. During these years a certain number of locomotives was ordered abroad. To expedite production it was decided to make use of the tried and ready design of 1-5-0 locomotives which were built for Russian railroads during the First World War.

Building of new 1-5-0 locomotives took place in 1944-1945. They were identified as Ye^{a} and Ye^{m} series (figure 25). In their principal dimensions they do not differ from the Ye^{1} locomotives, but a number of individual components were redesigned. There were modifications in the internal and external fixtures of the boiler, in the superheater, the grate, the frame, drifting devices, and in the brake system. Furthermore, these locomotives had stokers and centralized lubrication of journal boxes.

Due to the use of a mechanical stoker and a more powerful superheater, as well as an increase in the weight on drivers, the power rating of this locomotive was 20-25 percent greater than that of the Ye^{1}. Ye^{a} and Ye^{m} locomotives differ from each other in the construction of guides and cams and of the other parts in driving and other mechanisms. The Ye^{m} comprised the second large order of these locomotives. Some of them had a completely coated cylinder block, and in some others, this block was cast together with the frame.

Besides 1-5-0 Ye locomotives, in 1916 railroads received 80 Belgian 1-5-0 locomotives, which were identified as the F series (figure 2o). These locomotives had a four-cylinder, single-expansion engine with a crank shaft. The front truck was connected in the same manner as the front truck of S locomotives, but it had a spherical bearing. There were two gates in the firebox which had a cylindrical instead of a flat roof sheet. It was not possible to install a flat roof sheet because of the confined space as perscribed by Belgian standards for Belgian railroads, for which this locomotive was designed. In order to increase space for steam the cylindrical roof was somewhat raised and transition to the tube part of the boiler was accomplished by means of a conic course. Instead of return cranks which could not be used because of lack of space, internal eccentric rods were installed which gave oscillating motion to the links by means of special shafts. Such an inconvenient arrangement was later replaced by a normal one, and our large allowance for space permitted the installation of outside cranks of the regular type.

After the change over from 1,435 millimeter gauge to the normal 1,524 millimeter gauge, these locomotives were delivered to the Yekaterininskiy Railroad.

The successful operation of these locomotives on curves enabled them to be used successfully on the mountainous Simferopol'-Sevastopol' section which abounded in curves, steep grades and tunnels. Before the shops in Simferopol' received the 2-4-0 M locomotives in 1928-1929, the F locomotives were used also in passenger service.

Characteristics of the 1-5-0 Ye and F locomotives are given in table 11.

[Table 11 on the following page]

10. 1-5-0 SO LOCOMOTIVES

As ~~it~~ was mentioned before the need of the USSR railroads for freight locomotives of the 1-5-0 type was felt for quite some time. Even during the First World War a large number of 1-5-0 Ye locomotives was delivered to Russian railroads.

With the load from wheel pairs on the rails identical with that of the E locomotives, and developing the same tractive force, the 1-5-0 Ye locomotives did not require reconstruction ofthe roadbed of reinforcement of coupling devices, thus they could operate

Table 11

CHARACTERISTICS OF 1-5-0 Ye AND F LOCOMOTIVES

Series	Cylinder diameter in mm		Stroke in mm	Drivers diameter in mm	Pressure in atmospheres	Heating surface in square meters		Grate area in square meters	Weight in tons	
	High pressure	Low pressure				Evaporating	Superheating		On drivers	In working order
Trans-caucasian RR 1895	2x381	2x635	711	1,270	12	168	--	3.46	66.5	75.0
Ye^f	2x635	--	711	1,321	12.67	242.5	70	6.0	81	91
Ye^s	2x635	--	711	1,321	12.67	242.5	70	6.0	81	91
Ye^k	2x635	--	711	1,321	12.67	242.5	70	6.0	81	91
Ye^l	2x635	--	711	1,321	12.67	242.5	70	6.0	81	91
Ye^{pf}	2x710	--	711	1,321	12.67	300.0	118	6.0	90	100
Ye^a, Ye^m	2x635	--	711	1,320	12.67	229	75	6.0	87	99
F	4x500	--	660	1,450	14	262	61	5.1	88	105

under the same conditions. At the same time, these locomotives were faster. Locomotive-building plats which built E and S^u locomotives could begin building 1-5-0 locomotives without drastic retooling. All this was taken into consideration in the process of designing and building the Soviet 1-5-0 locomotive, which was identified as SO series (Sergo Ordzhonikidze). The design of this locomotive provided for maximum utilization of E^m locomotive parts. This heritage of design was very convenient in the building as well as in the operation of the locomotive.

The design of the locomotive was prepared in the Bureau of Powerful Locomotives of the Leningrad Institute of Railroad Transport Engineers under the direction of Professor K.A. Shishkin and with the participation of Doctor of Technical Sciences P.A. Slitikov, Docent V.M. Panskiy, Engineer A. A. Kleynman, and others. Detailed elaboration of the design and working drafts were prepared at the Khar'kov Locomotive-Building Plant under the direction of P.M. Sharoyko. On 7 November 1934 the plant delivered the first SO locomotive (figure 27). In January 1937 this locomotive was tested on the test ring of the TsNII under the direction of Doctor of Technical Sciences Professor V.F. Yegorchenko. Tests established that actual power of the locomotive exceeded its rated power. In 1935 several plants began mass production of the SO locomotives. The engine of the SO locomotive is practically identical with the engine of the E^m locomotive, differing only in the design of the main rod and side rods, and in the reinforced guides and crankpins. The same wheel-pairs were used in the running gear, but the axle of the driving pair was reinforced; the journal box guides and spring suspension, in part, were the same. The front truck is interchangeable with the front truck of the FD locomotive. But

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the boiler of the SO locomotive had a new design. The flat sheet roof of the firebox was replaced with a cylindrical sheet. The grate area was increased to 6 square meters and the firedoor opening was increased to provide for future installation of a mechanical stoker. The superheater is more powerful; it is contained in 50 flues.

In test runs the SO locomotive developed tractive force 8 percent greater than the tractive force of the E^m locomotive under low speeds; under high speeds the comparative increase in tractive force was 35 percent. The increase in tractive force permitted raising the speed on a standard grade by 30-35 percent with an increase in the train weight of 6-7 percent. Such different results obtained from two identical engines represent the most convincing proof of the superiority of the 1-5-0 type over the 0-5-0 locomotive type.

In SO locomotives, which subsequently were ordered into mass production, the superheater was given additional capacity through the installation of 2 more superheating elements with a total number of 52 flues. In steam consumption and in the efficiency of the boiler and of the locomotive itself the SO locomotive was also superior to the E^m locomotive.

In further operation of SO locomotives (identified as the SO17 series with a wheel-pair load of 17 tons) a certain weakness of the frame was detected; in cross sections of side frames the frame was identical with the frame of the E^m locomotive, the question of frame reinforcing was taken up by the TsNII and, beginning with 1938-1939, SO locomotives were built with a reinforced frame.

Main rods and side rods were redesigned to accomodate floating bushings.

On 1 March 1936 the Kolomna Plant delivered the first two experimental SO locomotives with complete condensation of exhaust steam (figure 28). A purpos of this, it should be recalled that the first locomotive in the world with condensed steam was built in Russia by the same plant as far back as 1891.

B.S. Pozdnyakov, A.M. Kozyakin, A.A. Kirnarskiy, T.I. Grin' and D.S. Kryzhanovskiy were the designers of the SO locomotive with steam condensation. Because of the repeated use of the same water, with the addition of an insignificant amount of fresh water to compensate for leakage, a locomotive with steam condensation cuts down water consumption about 20-25 times as compared to regular locomotives, and it can run without taking on water for 800-1,000 kilometers and in individual instances even up to 3,000 kilometers.

The value of steam condensation in a waterless region is tremendous. It is enough to point out that in some localities the cost of a cubic meter of water is up to 5 rubles 40 kopecks in 1947 prices. Condensation equipment of the SO locomotive insures complete condensation of steam at temperatures up to 40 above zero. To produce boiler draft, instead of the usual funnel which passes the exhaust steam into the air, SO locomotives with steam condensation has a fan draft produced by a turbine with up to 4,000 revolutions per minute.

The fan draft is very powerful and utilizes the energy of exhaust steam more efficiently. The draft in the boiler is even contributing to economy in fuel consumption and permiting the use of coal of the lowest quality. The turbine which drives the fans of a tender-condenser develops up to 7,000 revolutions per minute. Much attention was paid to oil seals in the SO locomotives with steam condensation, so that no oil would get in the boiler when condensed steam was admitted into the boiler. Pumps of piston type are used for feeding the boiler with condensed steam. In December 1936 an SO17-635 locomotive with steam condensation made an unprecedented run from Moscow to Vladivostok and return, having covered the distance of about 20,000 kilometers with an average 24 hour run of 450 kilometers. (Later, in the weighing of SO locomotives with steam condensation equipment loads of 19 tons from a driving wheel pair were determined: therefore, these locomotives were given SO19 series identification.)

SO locomotives with steam condensation were built by the Khar'kov and the Voroshilovgrad plants, and tender-condensers for them were produced by the Kolomna plant.

These locomotives have their greatest value in arid regions and also in the regions where water is of poor quality. Their shortcoming lies in the difficulty experienced in maintenance and overhaul, the cost of which is 60-70 percent higher than of locomotives without steam condensation. Since 1940-1941 SO locomotives have been built without steam condensation (figure 29). The advantages, proven in practical operation, of fan draft, independent of steam condensation, resulted in the use of this type of draft even without steam condensation installation. A new version of SO locomotives appeared; this version was identified as series SO18, with a wheel-pair load of 18 tons.

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During the Great Patriotic War the fan draft as utilized on SO18 locomotives was of great importance because it permitted the use of fuel of the lowest quality. However, it should be noted that fan draft, with its many positive qualities, still has some defects, such as its complexity in comparison with the exhaust funnel type of draft, high initial and repair cost, greater weight, and, finally, the fact that it causes higher counterpressure on the pistons of the engine during exhaust stroke, which somewhat decreases the power of the engine.

Characteristics of SO locomotives are given in table 12.

[Table 12 on the following page]

11. LOCOMOTIVES 1-5--1 FD

The idea of using on Russian railroads of locomotives of 1-5-1 type first arose in 1915. It belonged to N.L. Shchukin, who even then pointed out the necessity of not only increasing the weight of trains, but also of increasing their speeds on grades which should increase the hauling capacity of railroads. However, at the time a progressive idea of building 1-5-1 locomotives and even of 1-5-0 locomotives met strong opposition from a conservative group of specialists. The only argument against the 1-5-1 type that at the time had a certain worth was in inability of many roundhouses and turn tables to take care of locomotives with such a long wheel base. After much wrangling 1-5-0 type was accepted for production.

The socialist reconstruction of national economy and the uninterrupted growth of industry and agriculture required that rail-

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Table 12

CHARACTERISTICS OF 1-5-0 SO LOCOMOTIVES

Series	Cylinder diameter in mm	Stroke in mm	Drivers diameter in mm	Pressure in atmospheres	Heating surface in square meters		Grate area in square meters	Weight in tons	
					Evaporating	Superheating		On drivers	In working order
SO17	650	700	1,320	14	227	97	6.0	87.5	97
SO19	650	700	1,320	14	227	97	6.0	94	104
SO18	650	700	1,320	14	227	97	6.0	90	100

road transport vitally increase its hauling capacity. As early as 1928-1930, that is five years after the beginning of mass building of E locomotives, this type of locomotive became inadequate for the traffic which was increasing year by year, especially on the most important main lines.

A Special Technical Bureau which was organized in 1930 as one of the auxiliary agencies of the NKPS embarked on the program of technical and economic research and calculations which had to serve as groundwork for designing and building new, and first of all, powerful freight locomotives. At the end of April 1931 this Technical Bureau worked out a rough draft of a design of a new freight locomotive of 1-5-1 type with the load from a wheel pair of 20 tons. This locomotive was supposed to combine a great tractive force, high speed, the ability to operate with the then existing helical suspension and on low quality fuel, without causing immediate reconstruction of the tracks and the roadbed. On 1 May 1931 this Bureau, in collaboration with the Central Locomotive Designing Bureau of the NKTP, began preparation of working drawings of this locomotive. The work was made extremely complicated by the need of solving a whole series of technical problems inherent in designing a brand new type of a powerful locomotive meeting all the requirements of modern, advanced technology. In 100 work days the design of the new locomotive was complete. In August the blueprints were turned over to the Voroshilovgrad Locomotive-Building Plant which was entrusted with the honorable task of building the first 1-5-1 locomotive. Three other plants participated in building this locomotive: the Kolomna plant, which furnished steel castings; the Sormov plants which delivered pressed boiler sheets;

and the Izhorsk plant, which was responsible for rolling side frames. Building of the locomotive was completed in a record short time -- 70 days. At the same time the plant cleaned out the backlog of its other scheduled production. In honor of Feliks Edmundovich Dzerzhinskiy the locomotive received the identification of FD series (figure 30). On 3 November 1931 the first FD locomotive pulled the train bearing a delegation of plant workers from Lugansk to Moscow, ~~which workers~~ on 6 November reported to the Government the delivery of the first FD locomotive into service.

Producti n of powerful FD locomotive in a period hitherto unprecedented in history for its brevity -- altogether 170 days -- could be accomplished only under socialist organization of labor.

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In detail design this locomotive represented a tremendous step forward. Introduced for the first time were: a firebox with built-in combustion chamber, a stoker, a powerful superheater with fine pipes, a reducer consisting of many valves, installed beyond the superheater, and many other details and assemblies. Steam cylinders, forming a block, are mounted on the girder type frame and they serve as the front support of the boiler and at the same time as a bracket for the frame. The spring suspension is divided into three independent groups, forming a static system under which the distribution of load on axles is accomplished automatically, instead of requiring special adjustments. In the driving mechanism guides of several bars, main rods on floating bushings, and many other parts of more improved design were used. The principal units of the locomotive, including boilers, cylinders, parts of the driving mechanism and running gear, are interchangeable with the same units and parts of the powerful passenger 1-4-2 IS locomotive. Locomotives were built with 6 axle tenders. Tests conducted with the FD locomotive and its comparison with E^u locomotive showed that power increased two-fold, that tractive force permitted increasing the weight of the train 15 - 20 percent, and that average commercial speed increased more than 50 percent. The FD locomotive develops up to 3,000 horsepower.

The first FD locomotives had a frame which was processed with autogen cutting. The cut out areas at first were not worked over, and zones of heat influence were not taken off, while the frames themselves were not annealed. In operation thermic cracks appeared on frames. To avoid them, the technological process of frame making was changed, and since 1938 frame cross members have been reinforced. Tests of FD frames were conducted in 1939 - 1940

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by a group of dynamics specialists of the TsNII -- S. S. Zol'nikov, K. P. Korolev, S. M. Kucherenko and S. F. Markevich -- with an oscilograph recording of the results. These tests made it possible to ascertain stresses in locomotive girder frames.

Mass building of FD locomotives by the Voroshilovgrad Plant imeni October Revolution was carried out until 1941. Starting in 1938 a whole series of modifications in design took place, the most important being a change to all-welded boilers with flues of large diameter and with a superheater of one-cycle pipes in 6 flues, replacing a five-valve reducer with a six-valve one, increase in the number of cross members of the frame mentioned above, replacing elliptic springs with wider springs with a greater number of leaves, replacing blades in spring shackles with bushings, a complete change over to disc wheels, etc. FD locomotives built since 1938 are identified as FD 21 series, which means that their load from a wheel pair is equal to 21 tons. Actually, this load is less than 21 tons. It was caused by reducing the weight of the boiler 3--3.5 tons in the welding process and using disc wheels. Lead poured in counterbalances of the driving pair of FD locomotive weighs 1408 kilograms in spoke wheels, 689 kilograms in disc wheels.

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In 1937-1939 two experimental FD locomotives were built: one was equipped with steam condensation, and the other - with a fuel system designed for coal dust fuel. The coal dust fuel system in spite of its bright prospects for the future, so far has not left the stage of experimentation. The consumption of steam is still too great per unit of coal dust.

For comparison of FD locomotives with T^a and T^b locomotives their characteristics are given in Table 13.

Table 13 - Characteristics of 1-5-1 FD Locomotives

Series	Cylinder Diameter in mm	Stroke in mm	Drivers diameter in mm	Pressure in atmospheres	Heating Surface in Sq. Meters: Evaporating	Heating Surface in Sq. Meters: Superheating	Grate Area in Sq. Meters	Weight In Tons: On Drivers	Weight In Tons: In Working Order
FD 20	670	770	1500	15	295	139	7.0	101	134
FD 21	670	770	1500	15	250	122	7.0	104	138
T^b	700	760	1520	14	340	150	7.34	115	156
T^a	700	760	1520	17	381	160	8.00	115	168

12. 1-5-0 L Locomotives

The turning point in the course of the Great Patriotic War came in 1943; after this a partial re-evacuation of many industrial enterprises was started, and among them the Kolomna Machine-Building Plant imeni V. V. Kuybyshev.

In expectation of the immediate return of the country to peaceful labor after victory, a question arose as to what kind of locomotives would be built. First of all, it was necessary to select the type of locomotive and the load from driving wheel pairs upon the rails. SO locomotives, which have been in service for quite some time already, revealed certain defects in their running gear and the design of some of their units had to be reexamined. Besides, the SO locomotive engine, copied after the E locomotive engine without essential changes, with its diameter of valves inadequate for powerful locomotives, curved steam channels, etc, has already become obsolete. A special commission, composed of representatives of the Ministry of Communications and of the Ministry of Heavy Machine-Building, with the participation of workers from the TsNII, was formed. This commission was charged with the task of selecting new types of locomotives for the immediate postwar period.

The commission came to the conclusion that transport's most urgent need lay in freight locomotives. Upon consideration of the fact that the USSR railroads, much damaged by war action, could not, because of the condition of the upper part of the roadbed and bridges, immediately be adapted to large loads from wheel pairs upon the rails, that is of 20 tons and above, the Commission approved the load from the wheel pair upon the rails of 18 tons for locomotives of planned postwar construction.

In March 1944 rough drafts of designs of 1-5-0 locomotives with such loads and with drivers 1500 millimeters in diameter were submitted by the Kolomna Plant, by the Central Administration of the Locomotive Services of the NKPS, and by the Central Scientific Research Institute of Railroad Transport (TsNII). The last design called for maximum use of the FD locomotive parts.

In the process of technical elaboration of the design it was established that with drivers having a diameter of 1500 millimeters and with the load of 18 tons from a wheel pair it was possible to install a more powerful boiler than on SO locomotives. The essential difference between the designs of the Kolomna Plant and of the TsNII was in the location of the flexible front support of the firebox. According to the Kolomna design, this support was located behind, while in the TsNII draft ahead, of the fourth axle. The consideration of the drafts lasted until the end of 1944 and in March 1945 the Ministry of Transport Machine-Building, having approved the Kolomna design, commissioned the plant to build the first trial model of the locomotive. The plant at the time was engaged exclusively in overhauling locomotives, and it was necessary to overcome great difficulties in order to organize building of an entirely new type of locomotive. But that could not stop the plant in performing a task of such great importance, and as a result of the insistent efforts of the personnel of the plant by September 1945 the first trial model was built.

The locomotive, which at first was identified as P-32 series, was sent to the test ring where it was exhibited to the Minister of Communications, L. M. Kaganovich, and to the Minister of Transport Machine-Building, V. M. Malyshev. By that time a large number of Ye^{a} locomotives of foreign construction had already arrived in the USSR, and in the process of discussion the question arose as to whether these locomotives should also be built by Soviet plants. It was decided to run parallel tests of Ye^{a} and P-32 locomotives. Two P-32 locomotives were tested; number 2 was tested for tractive force, and number 1 for road operation (in the region of Tikhoretskaya Station of the North-Caucasian Railrads); the tests were completed by March 1946.

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The road tests revealed not altogether satisfactory operation of the front truck. However, this failure could not be ascribed to poor design, because the truck was of the same type as of FD and SO locomotives. It developed that the truck in question had been taken from under an SO locomotive and installed on the P-32 locomotive that was being tested and that this truck was in an unsatisfactory condition (especially in its centering action mechanism). After the locomotive had been balanced, the results were satisfactory. Comparative tests of P-32 and Ye[a] locomotives gave very favorable results for the first locomotive. The P-32 locomotive turned out to be more powerful and more economical than the Ye[a] locomotive. Thus, the question of whether these locomotives should continue to be built at the Soviet plants was answered in the negative, and by August 1946 the Bureau of Design of the Plant completed preparation and correction of blue prints for serial building.

In the same year of 1946 the mass production of P-32 locomotives was begun. The first locomotives were delivered to the railroad nearest to the Plant (the Moscow-Ryazan' railroad), which was very convenient for the plant since it made it possible to observe locomotives in actual service and to accumulate practical experience which could be taken into consideration in building other locomotives. The results of weighing conducted in November-December 1946 established that the total weight on drivers of the first P-32 locomotives was about 94.5 tons instead of the 91 tons planned for in the design. In the winter of 1946-1947 work on reducing the weight of the P-32 locomotive was started. The frame, the boiler, decks and other parts were reduced in weight as much as possible. By April 1947 the Plant succeeded in reducing the weight on drivers of newly built

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locomotives to 90 tons with the total weight not over 103 tons. In weighing one of the locomotives it was revealed that the load for a driving wheel pair fell to 16 - 15.5 tons. In searching for the causes of such an undesirable distribution of loads it was discovered that the main structure of the locomotive, suspended on springs, was in a somewhat too high and not quite horizontal position, and that the front part of the locomotive in individual instances was about 20 millimeters higher than the rear part. Further investigation established that in the manufacture of springs the camber of the springs without load was too great. Because of it in assembled spring suspension, the equalizers between the driving and the fourth coupled pairs were considerably out of line. The equalizers had to be adjusted with shims. When, in the process of manufacture, the camber of the spring was given the value called for by the design, the above mentioned defect was overcome. The wheels of the locomotive were of the disc type without the use of lead in counterbalances.

Because of the good traction and operational characteristics of new 1-5-0 locomotives of the Kolomna Plant ascertained in the one and a half year period which had elapsed, by order of the Council of Ministers dated 11 January 1947 the locomotives were identified as L series in honor of the name of their chief designer L. S. Lebedyanskiy (Figure [illegible]). In the same year (1947) L. S. Lebedyanskiy's work was awarded a Stalin prize. Simultaneously, the Council of Ministers approved the L locomotive for mass production. Some boilers for this locomotive are made by the Izhorsk plant. Tenders, in part, are built by the Bryansk Plant.

Characteristics of 1-5-0 locomotives are given in Table 14.

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TABLE 14

CHARACTERISTICS OF 1-5-0 L LOCOMOTIVES

Series	Cylinder Diameter in mm	Stroke in mm	Drivers diameter in mm	Heating surface in square meters: Evaporating	Heating surface in square meters: Superheating	Pressure in atmospheres	Grate area in sq. meters	Weight in tons: In drivers	Weight in tons: In working order
L First Order	650	800	1500	222	114	14	6	94.5	107.5
L Serial Building	650	800	1500	222	114	14	6	90	103

TABLE 15

CHARACTERISTICS OF 1-4-0 Sh[a] AND 1-5-0 SERIES 52 LOCOMOTIVES

Type and Series	Cylinder Diameter in mm	Stroke in mm	Drivers Diameter in mm	Pressure in Atmospheres	Heating surface in square meters		Grate area in square meters	Weight in tons	
					Evapo-rating	Super-heating		On dri-vers	In working order
1-4-0 Sh[a]	482	660	1448	15.8	165	45	3.8	64.0	74
1-5-0 52	600	660	1400	16	178	64	3.9	75.0	86

13. 1-4-0 Sh^a and 1-5-0 SERIES 52 LOCOMOTIVES

During the Great Patriotic War a certain number of 1-4-0 Sh^a and 1-5-0 Series 52 freight locomotives was delivered to the USSR railroads.

Locomotives of this series were built in foreign plants from 1942 to 1944. Their characteristics are given in Table 15.

14. EXPERIMENTAL 1-5-2 LOCOMOTIVES OF THE VOROSHILOVGRAD PLANT AND 1-3-0 + 0-3-1 LOCOMOTIVES OF THE KOLOMNA PLANT

At the end of 1948 and in the beginning of 1949 one experimental model of each type of locomotives was built. Their general appearance is shown in Figures 33 and 34, and their characteristics are given in Table 16.

A completely original engine is installed on the 1-5-2 Voroshilovgrad Plant locomotive. The cylinders are located at the center of the frame in a top position. In each cylinder there are two pistons moving in opposite directions. Power from pistons is transmitted through rocking arms and main rods mounted on the crankpins of the driving pair, which are mounted on each wheel on a 180 degree angle. The movement of reciprocating parts in the opposite direction creates conditions for best balancing of forces of inertia. A shortcoming of this engine lies in a certain complexity which it has; there is an increased number of swivel joints which receive total effort from the pistons, and steam channels have been lengthened.

The articulated 1-5-0+0-5-1 P-34 locomotive of the Kolomna Plant has, since the middle of February 1949, been in regular service on the Moscow-Kursk Railroad where it operates side by side with the FD locomotives. By the middle of April of the same year it had covered 12,000 kilometers and demonstrated its good qualities. The weight of the train pulled by this locomotive is 30 percent greater that the weight of the train pulled by an FD locomotive. The heaviest train pulled by this locomotive in winter operation on the Moscow-Kursk Rairoad was one of 3200 tons, while on the Moscow-Ryazan' Railroad the maximum weight of the train was 3800 tons. In fuel consumption this type locomotive is superior to the FD type because of a high degree of superheating, large tractive force, and good drifting operation, which is effected through by-passing devices of a new design. Locomotive crews state that this locomotive is noted for its smooth mition and good negotiation of curves. Universal joints of intake and exhaust manifold operate quite satisfactorily after they have been adjusted on a special stand. Many parts of this locomotive are interchangeable with parts of the 1-5-0 L locomotive (wheel-pairs, front truck, journal boxes, some rods, floating bushings, parts of spring suspension, brakes, fixtures, and parts of other assemblies). The firebox has no combustion chamber, but in spite of this the distribution of the boiler load on driving trucks is quite satisfactory. The load from a wheel-pair upon the rails reaches 19.5 tons.

In articulated locomotives the possibility of utilizing the balancing advantages of multi-cylinder locomotives is precluded, but good balancing is effected in them through weight reduction in the driving parts of each engine.

In addition to these locomotives, a 1-5-2 locomotive with a regular engine was built by the Ulan-Ude Plant. Both cylinders of the locomotive, forming a block, are cast in one piece.

Table 16. Characteristics of 1-5-2 and 1-3-0 + 0-3-1 Locomotives

Type	Cylinder Diameter in mm	Stroke in mm	Drivers Diameter in mm	Pressure in Atmospheres	Heating Surface in Square Meters		Grate Area in Square Meters	Weight in Tons	
					Evaporating	Superheating		On Drivers	In Working Order
1-5-2	2x250	4x645	1500	17	324	184	8.2	112	162.5
1-3-0 + 0-3-1	4x500	800	1500	14	282	147	7.8	117	147.0

15. TEST CHARACTERISTICS OF FREIGHT STEAM LOCOMOTIVES

A general comparative evaluation of the freight steam locomotives which were described in this chapter and which were subjected to a series of tests, is given in Table 17. (Table 17 was compiled by V. A. Pavlov)

This table gives values of maximum crank power $N_{k(max)}$ under fixed conditions of operation (standard boiler settings z_m and speeds v corresponding to $N_{k(max)}$).

Efficiency coefficients listed in the table, however, cannot serve

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as criteria for the quality of locomotives, because some locomotives were tested on coal and some on fuel oil.

Table 17. General Test Characteristics of Freight Locomotives (Power Corresponds to test z_m)

Type and Series	z_m Kilograms per Square Meter per Hour	v Kilometers per Hour	$N_{k(max)}$ Horse Power	Percentage	Fuel Kind	Fuel Q_n^p
0-4-0 O^v	45	30	560	5.2	Fuel oil	9900
0-4-0 O^c	45	20	500	4.6	Fuel oil	9900
0-4-0 O^p	40	30	480	5.2	Briquette	7750
0-4-0 O^{ch}	40	30	600	-	Coal	-
0-4-0 Y	45	60	1020	6.5	Fuel oil	10200
1-4-0 Shch	40	40	670	4.8	Coal	7700
1-4-0 Shch^p	40	40	620	6.0	Briquette	7750
1-4-0 Shch^{ch}	45	40	1130	8.7	Fuel oil	9810
0-5-0 E	55	40	1260	6.8	Fuel oil	10030
0-5-0 E^r	55	40	1300	-	Fuel oil	-
0-5-0 E^u	50	40	1320	6.275	ARSh 25% PZh	6549
0-5-0 E^m	50	40	1250	6.575	ARSh 25% PZh	6247
0-5-0 E^r	55	40	1360	5.775	ARSh 25% PZh	6433
1-5-0 Ye^s	55	30	1420	6.1	Yek.-Donets Coal	7200
1-5-0 Ye^A	55	40	1850	5.4	G	6820
1-5-0 Ye^{pf}	40	70	1690	7.45	PZh 25% ARSh	6930
1-5-0 SO 17	55	40	1760	6.775	ARSh 25% PZh	6640
1-5-0 SO 19	55	30	1510	7.475	ARSh 25% PZh	6337
1-5-0 52	50	30	1090	-	Coal	-
1-5-0 PT 31	55	80	2070	-	Coal	-
1-5-1 FD	55	50	2600	6.9	D	5613
0-3-0 T 0-3-0 Th^{ch}	45	20	970	6.9	Yek. Donets Coal	7200

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CHAPTER III

PASSENGER STEAM LOCOMOTIVES

16. GENERAL REVIEW

Railroad transport plays the largest role in passenger traffic in the USSR. About 95 percent of all passengers use railroads. Our four-axle passenger cars in service on main-line roads were always the best in the world in the thoroughness of their internal arrangement and passenger facilities and conveniences, as well as in smoothness of motion. At the same time they are the heaviest. On the average, there is about 0.6 - 0.7 tons of car weight per passenger seat, which is almost twice as much as in foreign passenger cars of coach type. Therefore, the necessity of pulling heavy trains was felt in our country much earlier than in other countries. In the nineties of the past century there was already a transition to passenger trains with three pairs of coupled wheels.

Until 1907 the passenger locomotive inventory of Russian railroads consisted, basically of compound locomotives, operating on saturated steam, of the 2-2-1, 1-3-0, and 2-3-0 types of P, N, A, and other series, which pulled passenger trains of 300 - 400 tons in weight. From 1907 to 1910 passenger traffic greatly increased and the management of railroads was forced to increase the weight of the trains. Because the power developed by passenger locomotives was not sufficient for the operation of such heavy trains, two locomotives had to be used on one train, which was economically unprofitable. The majority of railroads had to replenish their locomotive inventory with new, more powerful locomotives.

Almost all locomotive-building plants of the country were drawn into building more powerful passenger locomotives. The leading plants worked out many and various designs.

Since a considerable part of the railroad network was in the hands of private companies and each road could select any type of locomotives at its own discretion, the newly built locomotives were numerous and quite diverse in type.

Among the locomotive types built in accordance with the most advanced ideas in locomotive building, two individual groups soon took leading positions. One of them was built on the basis of the following principle. The roadbed, which represented the biggest part of the investment of the railroad and which, in most instances at that time, had a very poor upper structure, required large expenditures for maintenance in proper condition.

Hence, the most important consideration in the process of building locomotives of this group was to obtain from them a maximum smoothness of motion and a minimum of effect upon the roadbed. The most acceptable types of passenger locomotives satisfying the above conditions could only be those which possessed the combination of a two-axle front truck with a four-cylinder engine and crankshaft. Such locomotives had well-balanced driving and reciprocating engine parts, and had the least dynamic action upon the roadbed.

This point of view was shared chiefly by private railroads, the most advanced of which were the Ryazan'-Ural Railroad headed by A. Ye. Delakroa and the Vladikavkaz Railroad headed by V. I. Lopushinskiy.

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The other group of locomotives was built on a different principle. The adherents of the latter principle considered that fast and powerful locomotives would be well balanced with even a two-cylinder, single-expansion engine, and that instead of a two-axle truck, an articulated truck could be used without any damage. By reducing weight through the use of lighter engines and the use of a trailing or supporting truck it was possible to install a boiler of greater steam-generating capacity with a wide firebox, one of greater volume. This point of view was shared by the administration of state-owned railroads headed by Professor N. L. Shchukin. At the time the superiority of either of the groups was considered to be an open question.

Representative of the first group of locomotives were:

The 2-3-0 U and U^u locomotives with a four-cylinder compound engine, designed by the Putilovskiy Plant and built in the period from 1907 to 1912 for the Ryazan'-Ural Railroad (Figures 59 and 60);

The 2-3-1 Б ^{kh}, a semi-tank with a four-cylinder compound engine, designed by the Khar'kov Plant and built in 1908 for the Ryazan'-Ural Railroad (Figure 79);

The 2-3-1 L^p, with a four-cylinder single-expansion engine, designed by the Putilovskiy Plant and built from 1915 to 1926 for the Vladikavkaz Railroad and the Oktyabr'skiy Railroad (Figure 67);

The 2-4-0 M, with a three-cylinder, single-expansion engine, ordered by the NKPS, designed by the Krasnyy Putilovets Plant and built from 1926 to 1928 (Figure 70).

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The following locomotives comprised the second group:

The 1-3-1 S, designed by the Sormovo Plant, built from 1911 to 1916 for State-owned railroads (Figure 61);

The 1-3-1 S^V, designed by the Kolomna Plant, built in 1914, for the Warsaw-Vienna Railroad (Figure 62);

The 1-3-1 S^u, designed by the Kolomna Plant; these locomotives form a basic type of Soviet passenger locomotive; production of these was begun in 1925 and continues up to now (Figures 63 - 66);

The 1-4-2 IS, in production from 1932 to 1941, are the most powerful Soviet passenger locomotives (Figure 71).

The place between the above-mentioned two groups was occupied by fairly numerous 2-3-0 locomotives with two-cylinder engines: B, K, K^u (Figures 55 - 58) and others (1908 - 1912), which, having culminated in the most successful among them the K^u locomotive (Figure 58), could not progress any further because of the impossibility of the installation on them of boilers with greater steam-generating capacity and wide fireboxes for burning low grade coal. Later the combination of a two-cylinder, single-expansion engine with a two-axle truck was used in the fast 2-3-2 locomotives designed by the Kolonna and Voroshilovgrad plants (Figures 72 - 74).

During the course of almost twenty years these two trends in locomotive building were in constant competition and both had their own adherents in the persons of most distinguished specialists.

Adherents of the first group of locomotives, i.e., with multi-cylinders, crankshaft, and two-axle front truck, were:

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M. V. Gololobov, A. S. Rayevskiy, V. I. Lopushinskiy, A. Ye. Delakroa, and others.

Adherents of the two-cylinder, single-expansion engine with an articulated truck were N. L. Shchukin, S. I. Mikhin, B. S. Malakhovskiy, A. A. Zyablov and several others.

There is no doubt that locomotives with four cylinders are better balanced and act upon the roadbed less than the two-cylinder locomotives. But four-cylinder locomotives are of more complex construction, which makes their maintenance more difficult and increases the cost of repair and overhaul. The presence of expensive crankshaft which must be regularly repaired because it develops cracks, and which has to be replaced after a run of 100 - 150 thousand kilometers also increases considerably the cost of their operation. The experience has proven that disadvantages of the four-cylinder locomotives are not compensated by their advantages. Because of this the question of which of the two groups was more advantageous was decided in favor of two-cylinder, single-expansion locomotives.

The appearance of compound locomotives of the first group was episodic and none of them were found in wide use. But locomotives with simple engines of the second group (except the S^v) were built by the hundreds, and the S^u by the thousands. Having been most widely acclaimed, they determined all subsequent stages in the development of the passenger locomotive.

From the examination of dimensions called for by designs and of the data obtained in tests of two-cylinder locomotives built in our country it can be deduced that two-cylinder locomotives have not

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only advantages in design but also thermotechnical advantages over the four-cylinder locomotives.

The above statement is supported by the following instances.

In the first instance a comparison between the S and the U^u locomotives is made. With the same weight on drivers and with the same number of wheel-pairs the boiler of the S locomotive has a much greater steam-generating capacity than the boiler of the U^u locomotive (Table 18). This was because the reduction in weight, due to the use of a lighter two-cylinder engine, presented the opportunity to use a front articulated truck and a trailing supporting wheel-pair under the fire box.

[See following pages for table]

The number of square meters of total heating surface of the boiler in relation to the unit of useful volume of cylinders of the S locomotive is more than double the number of the U^u locomotive.

A comparison of the engines and boilers of both locomotives in tests conducted in 1913 on the Nikolayevskiy Railroad gave the following data. In the specific normal steam consumption (i.e. bringing its thermic value to 640 calories) per crank-horsepower per hour at the optimum steam-admission value the four-cylinder, compound engine had advantages over the two-cylinder only for speeds up to 60 kilometers per hour. (For the U^u - 8.2 kilograms and for the S - 9.5 kilograms). At 80 kilometers per hour both engines operated with practically the same degree of economy (the U^u - 9 kilograms and the S - 9.1 kilograms) and at 100 kilometers per hour the advantage was on the side of the simple engine (U^u - 10.2 kilo-

TABLE 18

COMPARATIVE CHARACTERISTICS OF U^u AND S LOCOMOTIVES

Type	Weight in Working Order in Tons		Boiler				Engine		Driving Gear
	Total	On Drivers	Pressure in Atmospheres	Heating Evaporating Surface in sq meters	Superheating Surface in sq meters	Grate Area in sq meters	Cylinder Diameter in mm	Stroke in mm	Drivers Diameter in mm
2-3-0 U^u	76	49	14	153	39	2.8	2x410 2x580	650	1730
1-3-1-S	76	48	13	207	52	3.8	2x550	700	1830

Ratios

	of Total Heating Surface to Total Weight in Working Order	of Grate Area to Total Weight in Working Order	of Total Heating Surface to Volume of Cylinders
Uu	2.53	0.037	0.373
S	3.42	0.05	0.808

grams and S - 9.1 kilograms). Thus, the engine of the S locomotive was faster and more economical at higher speeds.

In connection with the above-mentioned fact, it is of interest to cite some observations made during test runs of the U^u locomotives with large degree of steam admission and on oil fuel (Vestnik Inzhenerov [Messenger of Engineers] No 6, page 231).

Trip Number 837. Throttle open 1/10, admission 50 percent, speed approximately 80 kilometers per hour. Start at 6:55 o'clock; at 7:12 o'clock -- water at the lower nut; 7:20 -- much soot, speed drops to 69 kilometers per hour. Pressure drop from 14 to 12 absolute atmospheres. Throttle closed for 5 minutes, nevertheless steam pressure is inadequate and the trip ended because of drop in steam pressure.

Trip Number 839. Throttle wide open, admission 50 percent, speed approximately 50 kilometers per hour. Start at 1:50 o'clock; 2:33 -- water all the time at the nut; injection continuous; boiler pressure -- 12.5 absolute atmospheres; 2:35 -- two injectors used; steam at the lower test faucet; pressure 12 atmospheres. 2:37 -- boiler pressure -- 10 atmospheres. Run stopped.

Such a uniform picture described also all the other runs of this locomotive.

The S locomotive operated in an altogether different manner.

We cite observations made during run Number 777 (Direct data of the tests of the first series of the S 20 locomotive, 1916, pages 84 - 85). Throttle fully opened, admission 30 percent:

4 hours 3 minutes - speed 116 kilometers per hour; pressure 13.6 atmospheres

4 hours 6 minutes - speed 117 kilometers per hour; pressure 13.2 atmospheres

4 hours 10 minutes - speed 120 kilometers per hour; pressure 13.7 atmospheres

4 hours 12 minutes - speed 120 kilometers per hour; pressure 13.0 atmospheres

4 hours 15 minutes - speed 120 kilometers per hour; pressure 13.3 atmospheres

4 hours 19 minutes - speed 120 kilometers per hour; pressure 13.0 atmospheres

The engine of the U^u locomotive, by the way, in specific steam consumption at high speeds was also inferior to the original type of the 2-3-0 U locomotive, which had no superheating and which was faster.

Partisans of the four-cylinder locomotives explained the unsatisfactory results with the U^u locomotive altogether by defects intrinsic in this particular series stating that "the results of the tests give no reasons whatsoever to defame this type of locomotive per se" (Vestnik Inzhenerov [Messenger of Engineers] 1915, No 6, page 231).

Citing in defense of this locomotive several ideas of its designers, M. V. Gololobov and A. S. Rayevskiy, the adherents of this type, stated that they did not want to build a fast locomotive and that, on the contrary, this locomotive was designed for heavy passenger service (Tests of 1912 - 1914 on the Nikolayevskiy RR, Volume 1, 1925, page 210).

At speeds under 70 kilometers per hour the U^u locomotive was the most economical of all passenger trains which were in service at the time and with oil fuel the saving in consumption of fuel on long grades was 23 percent greater than the K^u and B locomotives, and 26 percent greater than the S locomotive. For high speeds the

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U^u locomotive is no good at all (Ibid, page 409). At moderate and low speeds the four-cylinder engine with crankshaft does not permit full realization of its advantages.

In the selection of the type of passenger locomotive a big role was played by the nature of the fuel for which both locomotives were designed. The U^u locomotive was designed for fuel oil and the S locomotive, with its large grate area, was designed for coal. But because coal, cheaper and more available even now, is the basic type of fuel of our railroads, the U^u could not find wide acceptance in this respect as well. On the contrary, S locomotives were most widely used by our railroads.

The cost of building compound locomotives, the power being equal, was approximately one and a half times higher.

This instance serves to illustrate the correctness of the views of N. L. Shchukin and his followers, whose service to the country consisted not only in creation of the most rational type of passenger locomotive but also in envisaging the path of its development for many years to come. The 1-3-1 locomotives are still being built in our country, almost for forty years.

From this fact it can be plainly seen what a tremendous event was the decision to switch from the 2-3-0 type to the 1-3-1 type, rendering the future of the 2-3-0 type absolutely hopeless. If the 1-3-1 type locomotive had not been built and if locomotive specialists had busied themselves exclusively with the task of improving the 2-3-0 type, the passenger locomotive inventory would have been brought to premature moral [sic] obsolescence. In this connection, some opinions expressed by several specialists, adherents

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of compound four cylinder locomotives, are quite interesting.

For instance, on page 19 of the first volume of a work depicting the history of the development of those types of locomotives which underwent the tests of 1912 - 1914 on the Nikolayevskiy Railroad the following is stated: "operation of the S locomotives with oil as fuel, for instance, on the Moscow-Kursk Railroad with its sharp curves, appears to me to be an error in technology. In the Tsarist times this error was explained by the predilection of N. L. Shchukin for these locomotives. He used all of the authority of a deputy minister to popularize S locomotives."

Further, in the same work on page 210, we read: "for our roadbeds with weak upper layers locomotives with balanced engines merit special attention. (This may lead to a notion that only a four cylinder engine with a crankshaft is a balanced one. In reality, a two cylinder engine is also a balanced one (author's note).) Moreover, the joint use of compounding with superheating entitles us to expect from the U^u locomotive also a considerable economy in fuel consumption. All this in 1913 forced us to envisage in the U^u series the probable locomotive type of the immediate future."

At the 23rd Consultative Conference of members of the Locomotive Service one of the adherents of the four-cylinder locomotives stated: "to blame in general locomotives of compound design with four-cylinder engines is to deprive yourself once and for all of any progress whatsoever in locomotive building." (Proceedings of the 23rd Consultative Conference of the Locomotive Service in 1923, page 159.)

The second example of the competition between the two groups can be observed in the comparison of the 2-3-1 ^{P} and 1-3-1 S^{u} locomotives.

Characteristics of both locomotives are given in Table 19. They indicate a considerable superiority of the L^{p} locomotive boiler in heating surface over the boiler of the S^{u} locomotive, but this superiority was achieved in the tube part of the boiler and not in the firebox, which in the S^{u} locomotive is slightly larger. The heating surface of the firebox of the L^{p} locomotive comprises 6.6 percent of the total heating evaporating surface, and on the S^{u} locomotive, 9.4 percent.

[See following page for table]

L^{p} locomotives were designed especially for oil fuel, and the S^{u} - for coal fuel. It was not possible to design a firebox of adequate volume even for oil on the L^{p} locomotive because of the limit on weight which could be transmitted to the rear truck without exceeding the load which is exerted by a wheel-pair of this truck upon the rails.

The inadequacy of the firebox volume made itself felt from the very first days of operation of L^{p} locomotives, i.e. as early as the first trial run on 30 April 1915 from Petrograd to Okulovka and return. More will be said about the results of this run on subsequent pages.

On fuel oil the boiler of the S^{u} locomotive was 6 - 7 percent more economical than the boiler of the L^{p} type. The average drop in temperature of gasses in the tube part of the boiler, with the consumption of the same quantity of fuel in both boilers, was

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TABLE 19

COMPARATIVE CHARACTERISTICS OF L^p AND S^u LOCOMOTIVES

		Boiler				Engine		Running Gear	Weight in Working Order - in Tons	
Type of Locomotives	Pressure in Atmospheres	Water Surface Heating in sq Meters	Superheating Surface in sq meters	Grate Area in sq Meters	Firebox Volume in cubic meters	Diameter and Number of Cylinders in mm	Stroke in mm	Diameter of Drivers in mm	Total	On Drivers
2-3-1 L^p	12	271	85	4.65	7.6	4x460	650	1840	97	52
1-3-1 S^u	13	197	73	4.73	8.0	2x575	700	1850	85	54

approximately identical under tests. (R. P. Grinenko, Results of Tests of Locomotives of 1-3-1 S^u and 2-3-1 L types, Direct test data, pages 76 - 85 and 104 - 118.) And since in both cases there was practically no difference in the heat capacities of combustion gasses, it could be concluded that the front part of the heating surface of tubes, which in the L^p locomotive were 200 millimeters longer than in the S^u, was not utilized with adequate efficiency, especially since the total number of tubes in the L^p is larger than in the S^u locomotive.

This example once again confirms the correctness of the deduction made by the Academician S. P. Syromyatnikov on the basis of profound analysis of the thermic process concerning the uselessness of increasing the evaporating surface by means of lengthening the tube part of the boiler.

Now it has been established that a four-cylinder, single-expansion engine because of its increase of losses, expends on the average 8.5 percent more steam than a two-cylinder engine. But the steam expenditure by the engine of the L^p locomotive exceeded the expenditure by the S^u locomotive engine by almost 30 percent.

Therefore, it must be concluded that the L^p locomotive engine, in spite of its several very good points, such as straight steam passages, a good design of inlet and exhaust systems and so forth, still was deficient in economy.

The data, cited by us, was collected from the results of scientific tests exclusively. A detailed commentary on the results of practical operation of L^p locomotives on the Moscow line of the Oktyabr'skiy railroads together with the S^u locomotives from 1924 to

1936 will be given on one of the following pages.

Hence, in this example the advantage again rested with the two-cylinder engine.

The three cylinder 2-4-0 M locomotives (Figure 70) were the last attempt to operate on our roads locomotives with a three-cylinder engine and a two axle front truck.

It is a known fact that this attempt was highly unsuccessful. Later M locomotives were considerably improved by the conversion of the engine into a two cylinder M^r.

The development of locomotives with a two-cylinder engine led to a highly improved 1-4-2 IS locomotive (Figure 71).

In order to form a judgement of the power of this locomotive, Table 20 gives its characteristics compared with the S and S^u locomotives.

A parallel comparison of the M and the IS locomotives cannot be made because of their wide differences. The 1-4-2 type of locomotive considerably excels the 2-4-0 type, because installation of a larger firebox is possible in the first type.

[See following page for table]

However, on the basis of the above-stated comparisons one should not come to a general conclusion that three-and four-cylinder locomotives are not economical because only a few of these types of locomotives were designed and built in our country, and we have had much less experience with them than with the two-cylinder locomotives which were subjected to continuous improvement.

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TABLE 20

COMPARATIVE CHARACTERISTICS OF S, S^u AND IS LOCOMOTIVES

Type of Locomotives	Pressure in Atmospheres	Boiler: Water Surface Heating in sq Meters	Boiler: Superheating Surface in sq meters	Boiler: Grate Area in sq Meters	Engine: Diameter and Number of Cylinders in mm	Engine: Stroke in mm	Running Gear: Drivers Diameter in mm	Weight in Working Order - in Tons: Total	Weight in Working Order - in Tons: On Drivers
1-3-1 S	13	207	52	3.8	2x550	700	1830	76	48
1-3-1 S^u	13	197	73	4.73	2x575	700	1850	85	54
1-4-2 IS	15	295	139	7.03	2x670	770	1850	133	80

The above-mentioned thermo-technical defects of the three- and four-cylinder locomotives might have been due to accidental reasons and weaknesses in individual design and construction.

But so far as the roadbed, track and bridges are concerned, the advantages of operation of four-cylinder locomotives in practical experience are not felt, because a great many of other factors influence the wear and tear of the track and bridges, other factors which completely outweigh the advantages described above.

For instance, it is a known fact that passenger trains comprise only about 10 percent of the total number of trains in operation on a line. Furthermore three coupled wheel-pairs of passenger locomotives in service on a line hardly comprise 0.5 percent of the total number of wheel-pairs using the line, in other words, they represent a very insignificant value.

For instance, the period of operation of L^p locomotives on the Oktyabr'skiy railroad was not noted for any decrease in the cost of repair and maintenance of the upper part of the roadbed and of bridges.

Tests which were conducted on the Oktyabr'skiy railroad with L^p and S locomotives operating at maximum speeds for the purposes of determining the effect on the upper structure of three tested bridges indicated that in value of dynamic coefficients of stresses the L^p locomotive did not have any advantages over the S locomotive. (Engineer I. M. Rabinovich, On the dynamic effect of some types of locomotives on the upper structure of bridges on the basis of results of special dynamic tests, conducted by the Bureau in 1924. Proceedings of the NKPS, issue No 13, Fifth collected works of the

Bureau of Engineering Tests, 1925.)

It was observed that the deleterious effect on the track was caused by the rear supporting wheel-pair of the locomotive with long wheel base, and especially the pair not balanced with the rest of the spring suspension system. In this respect the L^p and also the S^u locomotives in their effect upon the track were less favorable than the S locomotives. The author observed many times exceptionally strong shocks caused by hitting of the rear supporting wheel-pair against switches and rail joints when riding on the L^p locomotives at high speeds. Such shocks were never observed with the S locomotives.

At speeds of about 120 kilometers per hour a simple two-cylinder engine affords very good balancing, which fact is observed with our best passenger locomotives, the S and the S^u types, which are remarkable for their very smooth motion. Moreover, even in the fast 2-3-2 locomotives of the Kolomna and the Voroshilovgrad plants, which were designed for speeds of 160 - 180 kilometers per hour, the simple two cylinder engine found its use and was excellent in operation.

Track maintenance cost depends to a great extent upon the volume of freight traffic; with the increase in traffic it is necessary to strengthen the track. Furthermore, the wear of rails is greatly affected by the condition of tires and, especially, uneven wearing of car wheels.

It remains to make a few more observations in regard to the type of the track. In an explanatory note concerning the selection of a new type of passenger locomotive for the Vladikavkaz Railroad in 1915 it was stated: "the good qualities of the Prairie type locomotive (the reference is to the 1-3-1 S locomotive) in respect to power and simplicity of construction were known to the railroad, but the road was of the opinion that the articulated truck, with which these locomotives were equipped could in no way replace a normal two-axle truck, which was unconditionally necessary for numerous S curves and high speeds (for instance, over 80 versts an hour)." (The Vladikavkaz Pacific. Some information on the new passenger locomotive of 2-3-1 Pacific type, 1915, page 3.) This opinion at the time was fairly popular, and it arose in part due to certain difficulties which were observed in test runs of the first S locomotives on curves. However, as it was immediately ascertained, the defects were due not to the type of the truck but to excessively powerful springs (3,000 kilograms) of the centering mechanism used on the first S locomotives. After these were replaced with less rigid springs (about 470 kilograms) all defects were obviated, and since that time the truck operated almost perfectly. Nevertheless, several specialists unequivocally continued to consider the articulated truck as an inferior variety without substantiating this opinion with any convincing proofs. The use of the two-axle truck can be considered as fully justified only for the speeds above 130 - 140 kilometers per hour.

From the standpoint of the theory, which was evidently accepted also by the authors of the explanatory note of the Vladikavkaz 2-3-1 Pacific type, since they found it opportune to refer to this theory, the articulated truck, as the comparative dynamic calculations made by Professor A. O. Chechott indicated, is only slightly inferior to the two-axle truck. (A. O. Chechott, More About the Vladikavkaz Pacific, page 16.)

The length of turntables in many roundhouses, which limited the length of locomotives, also contributed to the popularity of the articulated truck.

17. 2-2-0 P and D^k LOCOMOTIVES

In the second half of the nineteenth century passenger trains were serviced mostly with 1-2-0 locomotives, which in power rating were close to their contemporaries, the 0-3-0 freight locomotives. The engines of these locomotives were two-cylinder, single expansion.

By the nineties, the pulling power of these locomotives ceased to keep up with the yearly increase in passenger traffic and the need for more powerful locomotives became apparent.

In 1891, on the initiative of A. P. Borodin and under his direction, a more powerful (for the period) passenger locomotive was designed for the Southwestern railroads. This was a 2-2-0 locomotive with a tandem four-cylinder compound engine and with a two-axle front truck. After all-around tests of the first locomotive of this type and satisfactory results in practical operation, it was approved and more locomotives of this type were built in the main railroad shops of the Southwestern railroads in Odessa. By 1894 six such locomotives with some improvements were built (Figure 35). In these locomotives, for the first time in Russia, the firebox had a flat crown sheet. The diameter of driving wheels was 2,000 millimeters. At the time, this was the fastest Russian locomotive. Before its appearance, only the old locomotives of the St. Petersburg-Warsaw Railroad with one driving pair had the diameter of 2,100 millimeters. In the coupling heads of the new Southwestern Railroad locomotives, instead of the usual bearings, bronze bushings were used. When the whole group of 2-2-0 locomotives with tandem compound engines was given a P series, the 2-2-0 Southwestern locomotives became known as P^b (Borodin) series.

In 1899 the Moscow-Vindava-Rybinsk Railroad gave an order for locomotives of this type to the Kolomna Plant. Thirty of them, somewhat improved and altered, were built between 1897 and 1900; they received the identification of P^r series. The driving wheel diameter, because the tires were made thicker, was increased to 2,010 (Figure 36). Between 1902 and 1905 12 P^r locomotives were built by the Kolomna Plant for the Warsaw-Vienna Railroad which had a 1,435-millimeter gauge.

The last and improved series of 2-2-0 locomotives with tandem compound engine were designed and built by the Putilovskiy Plant for the St. Petersburg-Warsaw and for the Southwestern railroads. These locomotives were built between 1897 and 1902 and they became known as P^p series (Figure 37). During this period all passenger and fast trains on the above-mentioned roads were serviced mainly by the P^p locomotives. After 1903, when more powerful passenger locomotives of the N^v series with three driving wheelpairs were introduced on the St. Petersburg-Warsaw Railroad, the 2-2-0 P^p locomotives, being inferior to the first in tractive force, were turned over to the second-class lines and to suburban lines. Some of them were transferred to the Baltic Railroad where they were in service between St. Petersburg and Oraniyenbaum until 1908.

Because of the complexity of the tandem compound engine and

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of the difficulties experienced in maintenance and overhaul of this engine, attempts were made to build 2-2-0 locomotives with two-cylinder compound engines. In 1891 the Kolomna Plant built 19 such locomotives for the St. Petersburg-Warsaw Railroad. They received the designation of D^k series (Figure 38).

A radial-pendulum steam admission mechanism was used in these locomotives. Actual operation and special tests of these locomotives indicated that they did not possess any advantages over the 1-2-0 locomotives in pulling power, but they consumed more fuel. Therefore, no more of them were built.

The second 2-2-0 locomotive with a two-cylinder compound engine was the one built in 1902 by the Rostov main railroad shops of the Vladikavkaz Railroad for secondary lines. They turned out to be uneconomical in consumption of fuel, and because of it their building was stopped. These were the last on our railroad passenger locomotives for wide gauge track with two driving wheel-pairs.

[See following page for table]

18. 1-3-0 N AND Ya LOCOMOTIVES

Further development of passenger locomotives with two coupled wheel-pairs could not give any noticeable increase in their draw-bar power.

On some railroads, and especially on the Nikolayevskiy Railroad, the weight of trains by the nineties of the last century increased so much that two locomotives with two driving wheel-pairs had to be attached to a train. For these reasons the Ministry of Communications commissioned Professor N. L. Shchukin to design a

TABLE 21

CHARACTERISTICS OF 2-2-0 P AND D LOCOMOTIVES

Series	Cylinder Diameter in mm		Stroke in mm	Driver Diameter in mm	Pressure in Atmospheres	Evaporating Heating Surface in Sq Meters	Grate Area in sq Meters	Weight In Tons	
	High Pressure	Low Pressure						On Drivers	In Working Order
P^b	2x338	2x500	600	2000	12	111	1.87	27	44
P^r	2x360	2x550	600	2010	12	141	2.2	29	50
P^p	2x365	2x547	610	2000	12	146	2.5	30	58
D^k	460	670	650	1980	11	146	2.46	26	52
D	440	660	600	1552	12	127	2.52	30	55.2

new type of passenger locomotive with three pairs of drivers and with tractive force of 12.5 tons per pair. A locomotive of the 1-3-0 type with a two-cylinder compound engine with radial-pendulum steam admission mechanism and with a front radial wheel-pair was approved.

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It is important to note here that the 1-3-0 type first appeared in Russia as far back as 1878, i.e. 14 years before its appearance in other countries.

In 1892 the Aleksandrovskiy Plant built two locomotives on N.L. Shchukin's design. They proved to be somewhat heavier than called for by the design with tractive force per pair of drivers up to 14.7 tons. According to the standards of the period such a load was inadmissible. Furthermore, there were some complications of legal character, because locomotives with only one or two pairs of driving wheels were considered to be of passenger type. Having given a special permission for the service of these locomotives only on the Nikolayevskiy Railroad which was outstanding in its exceptionally good condition of the right of way, the Ministry of Communications insisted on the limitation of the speed of these locomotives by the speed of freight locomotives, and only later did the Ministry permit raising the speed to 70 versts per hour.

However, no deleterious effects from exceeding the limits of the load upon the rails were observed and since 1895 the load of 15 tons on rails of 24 lbs per linear foot was acknowledged as permissible.

From this instance it can be seen that the locomotive in its development had to upset the conservative standards of tsarist Russia, literally fighting for its path to further progress. The occasion for fighting for a 15-ton tractive force in the Nd locomotive in 1892 arose again in 1907, when 16-ton tractive force was won by the Shch locomotive.

The speed limit of the Nd locomotive, established in 1892

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as 70 versts per hour, upon the publication of works of N.P. Petrov on the calculations of rails in 1914 was raised to 108 kilometers per hour with the same rails. Old 24-pound rails of the Ural plants, laid on the Nikolayevskiy railroad in 1890, served on many stretches until 1930, and on them 2-3-1 L^p locomotives with tractive force of 20 tons per pair ran at speeds up to 100-110 kilometers per hour without limitations and without any harmful after-effects.

The lack of symmetry of the two-cylinder compound engine caused some specialists to doubt the expediency of its use on fast trains. For the purposes of comparison of the compound engine with a single-expansion engine in 1895-1896 the Alexsandrovskiy Plant, while building 10 N^d locomotives, constructed two of them with single-expansion engines. They were identified as N^a locomotives. Their cylinders were of the same diameter as the high-pressure cylinders of the N^d locomotive (480 millimeters). Their service of five-year duration under identical conditions with the Nd locomotives demonstrated that they were not economical in the consumption of fuel. The N^a locomotives did not exhibit any special advantages in their design and construction. At the time of the first overhaul they were converted into compound locomotives.

In 1896 the N^d type was slightly redesigned and strengthened in cylinders. The sander, formerly located in front, was placed at its usual position on the boiler (figure 40). Locomotives of the N^d 1947 type were used only on the Nikolayevskiy Railroad where they serviced until 1910-1912, all passenger trains — from mail trains to fast expresses. The road still remembers the splendid service of these locomotives. Radial-pendulum mechanisms on some of them were replaced at the time of overhaul at the Aleksandrovskiy

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Plant with link and pendulum mechanisms. A few of the N^d locomotives also were in service on the Warsaw line of the North Western Railroads and on the Syzran'-Vyaz'ma Railroad.

In 1901 the N^d locomotive was redesigned by the Kolomna Plant. The radial-pendulum mechanism was replaced with the link-pendulum and, instead of the front radial wheel-pair a one-axle truck was used. The high pressure sliding valve was replaced with a cylindrical one. This locomotive was identified as the N^v series; the diameter of driving wheels was 1,900 millimeters (figure 41). For railroads with grades over 8-10 percent, which required less speed but greater traction force, N series locomotives were built with driving wheels of 1,700 millimeters in diameter. They were identified as the N^v series. Of the private railroads only the Moscow-Vindava-Rybinsk RR placed orders for these locomotives. At the request of this road some N^v locomotives were equipped with improved cabs. N^V and N^v locomotives proved to be successful and having been generally accepted were used for many years, eventually relinquishing their place to more powerful locomotives. They were built by all our locomotive-building plants.

In 1907-1908 the Moscow-Vindava-Rybinsk Railroad, at the suggestion of Professor A.O. Chechott placed an order with the Putilovskiy Plant for eight locomotives of the N series with a wheel diameter of 1,700 millimeters, with single-expansion engines and with superheaters. The first four locomotives were initially equipped with chamber type superheaters located in fireboxes and had one flue with a diameter of 299 millimeters. The poor operation of such superheaters caused conversion of locomotives to the flue system. The other four locomotive were built with the flue type superheaters.

It should be noted that this road was the third one after the Moscow-Kazan' RR and the South Eastern RR to introduce locomotives with superheaters. Locomotives of the Moscow-Vindava-Rybinsk RR with superheaters and single-expansion engines were identified as the N^P_p series. Almost simultaneously, the Sormovo Plant built for the Nikolayevskiy Railroad three N^P_s locomotives with superheaters of the Russin Notkin system and with wheels of 1,900 millimeters in diameter. In order to make driving wheel-pairs interchangeable with the wheels of the basic N^V and N^V series, locomotives of the N^P_p and N^P_s series had advancement cranks which, because of the change to internal admission-link blocks, were placed in the upper position of the links in forward movement.

Somewhat later, in 1909 - 1910, on the suggestion of N.L. Shchukin, the N^V and N^V locomotives were made more powerful. Elaboration of new designs was turned over to two plants: the Nevskiy, and the Kolomna. The two plants used altogether different approaches to preparation of the new design. N. V. Serebryakov at the Nevskiy plant retaining compound engine and saturated steam, increased the grate area and diameter of the low pressure cylinder, raising the pressure to 13 atmospheres. The improved locomotives of the Nevskiy Plant were divided into two groups according to wheel diameter — 1,900 millimeters and 1,700 millimeters; they were identified as the N^U and Nu series (figure 42).

On the design of the Kolomna Plant, 14 new improved N locomotives were built in 4 modifications: the N^p with single-expansion engine and a super heater (figure 43); the N^{shp} with direct-flow engine of single expansion with piston-valve steam distribution and with superheater; the N^{sh} (figure 44) with the same engine but without a superheater; and the N^k with a two-cylinder, compound engine without a superheater (figure 45). There were two locomotives of each kind, except the N^k, of which 8 locomotives were built for the Libava-Romensk Railroad. All locomotives had wheels 1700 Millimeters in diameter. Many new parts were used in these locomotives, because of which they differed from the N^v locomotives more than the N^u did.

That last feature contributed greatly to the popularity of the N^u locomotive designed by the Nevskiy Plant. We note here that the basic parts of the engine of the N^p locomotive of the Kolomna Plant (cylinders, driving mechanism, and steam distribution) were designed in such manner that they could be used in future modernization of the N^v and the N^u locomotives through reworking their engines to single expansion and superheating. Such modernization was carried out considerably later, in 1929-1930, when a considerable number of the N^v and the N^u locomotives were remodeled.

In 1910-1912 the Moscow-Vindava-Rybinsk Railroad ordered from the Putilovskiy Plant 8 locomotives of the N^v type but with superheaters. They were identified as N^{ch} series, and they proved to be fairly economical. However, it was established through tests that the low pressure cylinder, identical with the N^v locomotive cylinder, was not adequate.

On the N^u and N^{ch} locomotives, because of their compound engines, starting devices of Yemelyanov and Petrov systems, which at the time

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were the best known in world railroading, were installed.

In 1912-1914 almost all locomotives of the N series underwent tests, on the basis of which it became possible to evaluate them. The most powerful and the most economical was the N^{shp} locomotive. With the direct-flow engine the exhaust of steam is effected very rapidly, and, because of it, the cylinders do not have time to cool off. The compression rate was up to 90 percent, which, in the N^{sh} locomotive with superheating, resulted in decreased engine economy. But on the N^{shr} locomotives with superheating the same engine proved to be the most economical. However, sharp shocks caused by rapid escape of steam, led to rapid loosening of the cylinders and front part of the frame. For this reason the N^{sh} and N^{shp} were not widely used. Later, in 1922 and 1923, the direct flow engine with decreased compression was used in two experimental 0-5-0 E^{sh} locomotives. The N^{p} and N^{ch} locomotives also proved to be economical, but at low speeds the N^{ch} locomotive operated better, while at high speeds -- the N^{p}. Other locomotives, since they operated on saturated steam, were inferior to the first ones, with just average results in tests and in operation.

In 1896, the Nevskiy Plant designed and built for the Moscow-Yaroslavl-Arkhangel'sk Railroad 35 locomotives of the 1-3-0 Ya type with the single expansion engine and radial-Pendulum mechanism.

These locomotives were less economical than the N^{d} or N^{v} locomotives. In the following years these locomotives were also ordered for the Libava-Romensk Railroad, the Polessye Railroad, and the Trans-Caucasian Railroad (figure 47). In 1898-1900 the Moscow-Vindava-Rybinsk Railroad also ordered abroad 6 locomotives of the same kind. They were identified as the N^{R} series (figure 48). The radial-pendu-

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lum steam distribution mechanism, which had a by-pass radius to the cylinder, often broke down. Due to this defect it was replaced with the return-crank type of mechanism as in the N^d locomotive. These locomotives were not economical and they were converted in the Rybinsk main railroad shops to compound locomotives, which somewhat improved them.

Characteristics of the N and Ya locomotives are given in table 22.

TABLE 22. CHARACTERISTICS OF 1-3-0 N AND Ya LOCOMOTIVES

Series	Cylinder diameter in mm: High pressure	Cylinder diameter in mm: Low pressure	Stroke in mm	Drivers diameter in mm	Pressure in atmosphere	Heating surface in sq. meters: Evaporating	Heating surface in sq. meters: Superheating	Grate area in sq. meters	Weight in tons: On drivers	Weight in tons: In working order
N^d 1893	480	720	650	1,900	11	163	--	2.2	44	57
N^d 1897	500	730	650	1,900	12	163	--	2.2	45	58
N^v	500	730	650	1,900	12	152	--	2.2	45	58
N^v	500	730	650	1,700	12	162	--	2.2	45	58
N^u	500	750	650	1,900	13	157	--	2.6	50	62
N^u	500	750	650	1,700	13	157	--	2.6	50	62
$N^p{}_p$	540	--	650	1,700	12	114	32	2.2	43	56
$N^p{}_s$	540	--	650	1,900	12	124.5	36	2.2	45	58
N^{ch}	500	730	650	1,700	13	140	36	2.2	45	58
N^p	540	--	650	1,700	12	127	39	2.5	48	61
N^{sh}	500	--	650	1,700	14	167	--	2.5	46	59
$N^{sh}{}_p$	540	--	650	1,700	12	127	39	2.5	48	61
N^k	500	730	650	1,700	14	167	--	2.5	46	59
N^r	482	--	650	1,800	11	161	--	2.3	40.5	52
Ya	482	--	650	1,800	11	161	--	2.3	40.5	52

economy of operation. Also, no special advantages from the use of the two-axle truck were observed. For this reason the A^d and A^v locomotives, since they could not compete with the N locomotives, were not so widely used as the latter.

The second type of the 2-3-0 locomotives with the compound engine were those of the Zh series built for the Moscow-Kazan' Railroad by the Kolomna plant in 1901 (figure 51). These locomotives were superior to the A^v locomotives in their speed and their exceptionally smooth movement at high speeds. The first driving wheel pair had no flanges, and the truck had a centering device. In order to reduce weaving movements and secure proper steering on curves the locomotive was grasped in the rear by long tender guides, of the same kind as those used on many other locomotives of the Moscow-Kazan' Railroad, including the 0-4-0 (V) locomotives. Zh locomotives were also found on some State-owned Northwestern (Baltic Line) and Southwestern Railroads. They were built by the Kolomna, Nevskiy, and Khar'kov plants.

The first to introduce the use of superheating in Russia was Ye. Ye. Nol'teyn, who in 1902 introduced on the Moscow-Kazan' railroad the first locomotive operating with superheated steam.

This was a 2-3-0 Zh locomotive, which, after it had been equipped with superheating and a single-expansion engine, was identified as the Z [illegible] series (figure 52). The superheater of the first locomotive was of the chamber type and was located in the smokebox; it had one flue with a diameter of 285 millimeters. Two years later the Moscow-Kazan' Railroad received eight more locomotives of the same type, which differed from the first one in some parts. The chamber superheaters, which proved to be unsatisfactory because of chronic leakage in the flue and poor superheating, were replaced with the flue-type superheaters with four-flue two-cycle elements. As this first experience showed, superheated steam, because of its fluidity leaked considerably through valves, pistons, and packing. Thus, further development in the design of the locomotive engine operating on superheated steam amounted to a struggle against this leakage.

Z locomotives were produced by the Kolomna Plant for the Moscow-Kazan' Railroad until 1904.

In 1906 the Kolomna Plant built for the Southeastern Railroad 15 locomotives of the same type, but with larger cylinders having a diameter of 575 millimeters (figure 53). These were the KSh-series locomotives. On eight of these locomotives axle breakage was frequent. Because of the seriousness of this condition a special commission to ascertain the reasons for breakage was set up under the chairmanship of B. B. Sushinskiy and with the participation of N. A. Stazharov, who later became a professor at the Leningrad Technological Institute and the Military Transport Academy.

The commission came to the conclusion that axle breakage was caused by hydraulic shock of condensation water against the cylinders because of their increase in diameter, and by the inadequate dimensions of the axles caused by unsatisfactory specifications for their manufacture and acceptance.

In addition to the 2-3-0 locomotives discussed above some

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2-3-0 locomotives of American construction were in service at the same time on the Moscow-Korsk and Nizhniy Novgorod-Kursk railroads. These were identified as the V series and had dimensions close to those of the 1-4-0 Kh locomotives. They had four-cylinder engines with outside cylinders mounted one above the other, with the high-pressurecylinder above and the low-pressure cylinder below. As we have seen, the Kh locomotives had the opposite arrangement of cylinders.

From the standpoint of convenience of the steam-admission system, the arrangement of cylinders was better on the 2-3-0 locomotives, and this arrangement was used regularly on passenger locomotives. On freight locomotives, however, because of the smaller wheel diameter, this arrangement could not be made since it could not be combined with the legal clearances.

The 2-3-0 V locomotives had many defects in construction. Weakness of staybolts, breaks in iron eccentric yokes, cracks in the iron bearing of the truck, crude manufacture of parts, and so forth sharply differentiated them from locomotives built in our country. At speeds as low as 60 kilometers per hour, under the action of excessive counterbalances, driving wheels would completely lose their loads. But these locomotives were designed for speeds of 100 kilometers per hour ("Reports of the Twenty-Fifth Advisory Congress of the Locomotive-Service, pages 275-279") A distinguished Russian theoretician and an authority on locomotive dynamics A. S. Rayevskiy, not without a reason, called American locomotive building illiterate.

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Characteristics of A, Zh, and Z locomotives are given in table 23. [See table 23 on following page]

20. 2-3-0 F. B. K LOCOMOTIVES

The weaknesses of the A^d and A^v locomotives, which were initially designed for the Vladikavkaz Railroad, forced this road to work out the design for a new improved type of passenger locomotive, retaining the two-cylinder compound engine.

The designing was done by the Bryansk Plant under the direction of Engineer B. I. Lopusshinskiy. The locomotives built by the plant belonged to the 2-3-0 type; they were identified as the G series (figure 54). These locomotives were designed and built together with 1-4-0 Sh freight locomotives. They had the same boilers, cylinders, and other engine parts. Like the Sh locomotives, the G locomotives were ordered for the Vladikavkaz and the Chinese Eastern Railroad as well. They proved to be heavier than the design called for, and their traction force was up to 17 tons. Certain defects in construction and the above-mentioned excessive weight limited the use of these locomotives as well as of the Sh locomotives to the two-above-named roads. Later the G locomotives of the Vladikavkaz Railroad were remodeled by the Rostov main railroad shops for the single expansion engine, and superheaters were installed in them (G^p series). On the Chinese Eastern railroad the same locomotives were also converted to superheat, but the compound engines were retained (G^{ch} series).

In 1906, when ordering more powerful passenger locomotives from the Bryansk Plant, the Moscow-Kiyev-Voronezh Railroad selected the already-existent design of the locomotive, but on the suggestion

TABLE 23. CHARACTERISTICS OF 2-3-0 A, Zh, AND Z LOCOMOTIVES

Series	Cylinder diameter in mm		Stroke in mm	Diameter of driving wheel in mm	Pressure in atmospheres	Heating surface in sq. meters		Grate area in sq. meters	Weight in tons	
	High pressure	Low pressure				Evaporating	Superheating		On Drivers	In working order
A	500	730	650	1830	12	152	--	2.16	44	62
AV	500	730	650	1830	12	152	--	2.16	44	62
Zh	500	730	600	1700	12	166	--	2.3	44	64
Z	540	--	600	1700	12	150	31	2.3	44	64
KSh South-eastern	575	--	600	1700	12	--	--	2.3	--	--
V	2x356	2x610	660	1829	12	163	--	1.9	44	63

of the plant introduced several improvements and a change-over to the single-expansion engine and superheating.

The diameter of driving wheels was increased to 1830 millimeters. The first three trial locomotives were built in 1908. After these had been tested and the design had been worked over once again at the same plant by S. O. Rozenblum and N. F. Denisov the locomotive was built in its final form, and it was identified as the B series (figure 55). The main driving pair was the front one, as in the G locomotive. The diameter of the sliding valves was 230 millimeters -- the smallest used on Russian locomotives. The B locomotives were better than the G locomotives and they were noted for their high degree of economy and speed. They found considerable use, and they are in service on secondary railroads even at present.

In 1909 B locomotives were also delivered to the Warsaw line of the Northwestern railroads, which, seen after the introduction of the S locomotives, turned the B locomotives over to the Nikolayevskiy Railroad. When pulling fast these express trains showed an interesting peculiarity which was discovered in the experience of locomotive engineers (drivers). At a speed close to 70-75 kilometers per hour the throttle had to be closed and the screw had to be tightened towards the center, after which the throttle would be opened for a large valve setting and the screw would gradually lower itself to the working cut-off position (o.2-0.3). Only after this did the locomotive pick up speed, and then it easily developed speeds of 90 or 100 kilometers per hour or even more. Unless the above procedure was followed the locomotives would not develop more than 70 to 75 kilometers per hour. Evidently, in the steam passage channel

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certain eddies and dead spaces were created which hindered the formation of a pulsating flow of steam.

The B locomotives, having a deep and long firebox, operated especially satisfactorily on oil fuel. With coal as the fuel they suffered from frequent clogging of the tubes and the superheating elements which was facilitated by the small inside diameter of the tubes, 119 millimeters.

In the B locomotive we see the culmination of the gradual development of the A^{V} locomotive first into the G, and then into the B locomotive, in the same way that the 1-4-0 Ts locomotive was converted first into the more powerful Sh locomotive, and subsequently into the Shch locomotive.

Further improvement and development of the 2-3-0 Zh and Z locomotives led to the new more powerful K locomotive. The design of this locomotive was worked out by the Kolomna Plant in collaboration with the Moscow-Kazan' Railroad on the order of the latter in 1906-1907. The first K locomotives proved to be heavier than the design called for, and therefore they were used only on the Moscow-Kazan Railroad. In 1908 the Kolomna Plant reexamined the design in order to reduce the weight of the locomotive. The new design was approved by the Commission on Rolling Stock and locomotives for orders for state-owned railroads. The locomotives, the production of which began that year, found service on many railroads (figure 56). With a power rating close to that of the B locomotive, the K locomotive competed with the B for first place for two or three years. Railroads were given the right to choose between these two types which were almost equal in quality.

The design of this locomotive was very original in some respects. In order to increase the grate area the firebox was widened and was mounted above the frame. This made it necessary to raise the axis of the boiler to the level of 3100 millimeters above the rails. Such a high boiler position had never been used before on any of our locomotives. Until the appearance of the K type, locomotives having such a high center of gravity of the boiler were considered to be top-heavy and unstable. However, as experience has shown, although the amplitude of oscillation of locomotives with a high-set boiler is greater than for those with a low-set boiler, the frequency of such oscillations is considerably lower. The explanation for this is to be found in the fact that all shocks from the rails in the higher locomotives are absorbed faster by the spring suspension than in the low-set ones, and as a result there is less transmission to the frame. The high-set locomotives rock evenly and slowly when in motion, but in compensation for this they do not experience the frequent and sharp oscillations characteristic of locomotives with low-set boilers. The side pressure on the rails, especially on the curves, is also less pronounced with the high center of gravity than with the low. After the successful experience with the K locomotive a high position of boiler could no longer cause any doubts.

The engine was supported by the truck through a spherical bearing resting on the truck center plate, the top side of which was convex. Such construction proved to be insufficiently stable, and its lubrication was unsatisfactory. The lack of flanges on the first driving wheel pair and a small initial centering action of the truck gave the locomotive a tendency to weave while in motion, and this tendency could not be overcome with the use of tender guides on the Zh and Z locomotives of the Moscow-Kazan's railroad.

While continuing to build K locomotives, the plant in 1909 introduced certain modifications, of which the most important was the improvement of the central plate which was upturned, so that the convex side was in the bottom receiving the pressure from the center pin mounted on the part of the frame between the cylinders. This created conditions for better lubrication. The location of the spring of the first pair of driving wheels was also changed; it was taken from the upper position and placed under the journal box, where it occupied a position identical with that of the other springs. The sharp angle of the front side of the cab was removed and the front side of the cab was made flat as usual; the running board at the front was raised to an equal height all around the boiler for convenience in servicing the smokebox. The mounting of the firebox above the frame, which was not solid enough in the first locomotives, was considerably reinforced.

K locomotives of the 1909 type were also built by the Putilovskiy Plant. Two of them, delivered to the Nikolayevskiy Railroad, were equipped with a steam-distribution system of the Savel'yev type (figure 57). However, this system broke down frequently. In order to ascertain the reasons for these break-downs, tables or plans of velocities and accelerations of the swivel joints were made, and it was established that the acceleration of one of the joints was towards infinity. This was an obstacle to wide acceptance of the Savel'yev system.

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The diameter of the driving wheels, which in the K locomotives was 1700 millimeters, proved to be too small for high speeds, and the inadequacy of the diameter was found to be the reason for the gradual loosening of the locomotive mountings at a high number of revolutions.

In 1911 the Kolomna Plant built a more powerful boiler for this locomotive and increased the diameter of the driving wheels to 1900 millimeters. The locomotive built in 1912 was identified asthe K^u series (figure 58). This was the most powerful and the fastest Russian locomotive of the 2-3-0 type, but it was not accepted into service by any other road than the Moscow-Kazan' Railroad, for which it was built. The reasons for this were, first, the weaknesses in the construction of some parts of the driving system and of the running gear, the weight of which had to be considerably reduced, in order to comply with the order of the Ministry of Communications not to exceed a traction force of 16 tons per pair of driving wheels, and, second, the 2-3-0 type had no further prospects for the future, for by that time the 1-3-1 locomotive, much superior to any 2-3-0 locomotive, had already been built.

A special peculiarity of the running gear of the K^u locomotive was the absence of equalizers in the spring suspension. Each spring was a dependent one, and it was a combination of one elliptic spring with two helical springs. The locomotive was suspended on seven points, resting with the central bearing on the front truck and being supported by the six independent springs of the driving wheel pairs. The central bearing of the truck was again redesigned and was put in the same position as in the K locomotives of the

1906 type. This system of spring suspension, which could not be statically determinate did not justify itself, for it required careful adjusting in order to obtain the same traction from all the driving wheel pairs. The system of individual springs without equalizers has never been used since on any Russian locomotive.

The characteristics of the G, B, and K locomotives are given in table 24. [See table 24 on following page]

21. 2-3-0 U LOCOMOTIVES

Passenger traffic on the Ryazan-Ural Railroad was serviced in the main by the 2-3-0 A locomotives. The outlook for the increase in the weight of passenger trains forced the road at the beginning of the present century to start working on the design of a new, more powerful passenger locomotive. At that time technical research for the road was headed by a distinguished authority on rolling stock, A. Ye. Delakroa, who at the same time was the head of the locomotive department of the railroad. A. Ye. Delakroa, who shared the opinion concerning the advantages of four-cylinder compound locomotives with crankshafts over other types, initiated the introduction of such locomotives in Russia, first on the Ryazan-Ural Railroad, and later on other roads as well. However, in the article on the history of the development of the U and U^{u} locomotives ("1912-1914 Tests on the Nikolayevskiy Railroad.") not only was nothing said about the role played by A. Ye. Delakroa in the creation of these locomotives, but his name was not even mentioned. While working at an advanced age in the Bureau of Powerful Locomotives at the Leningrad Institute of Engineers of Railroad Transport, Doctor of Technical Sciences

TABLE 24. CHARACTERISTICS OF 2-3-0, G, B, AND K LOCOMOTIVES

Series	Cylinder diameter in mm: High Pressure	Cylinder diameter in mm: Low Pressure	Stroke in mm	Diameter of driving wheels in mm	Pressure in atmospheres	Heating surface in sq. meters: Evaporating	Heating surface in sq. meters: Superheating	Grate area in sq.meters	Weight in tons: On drivers	Weight in tons: In working order
G	510	765	700	1730	14	199	--	2.8	46	75
G^{P}	560	--	700	1730	12	169	47	2.8	46	75
G^{ch}	510	765	700	1730	14	169	47	2.8	46	75
B	550	--	700	1830	13	164	41	2.8	46	73
K	575	--	650	1700	12	162	40	2.7	46	72
K^{u}	575	--	650	1900	13	181	47	3.2	48	74

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A. Ye. Delakroa transmitted much of his experience to young specialists working under his guidance.

The detailed working out of the design for the U locomotive ordered by the Ryazan-Ural Railroad was done by the Putilovskiy and Khar'kov plants and, in part, by the Bryansk plant. In July 1903 the Engineering Board of the Ministry of Communications approved the design of the U locomotive submitted by the Putilovskiy Plant and prepared by M. V. Gololobov. This design was reported on to the Board by N. L. Shchukin, who at that time expressed the wish to have the outside high-pressure cylinders mounted back of the front truck so as to decrease the length of the valve rods to the normal. However, even though this suggestion merited attention, it could not be adopted, since that would have necessitated a considerable alteration of the whole design. The first U locomotive was built by the Putilovskiy Plant in March 1907 (figure 59).

The locomotives proved to be economical and had a very smooth movement. The experience of 1910 showed that the locomotive operated most satisfactorily with cut-offs of about 30 percent in the high-pressure cylinders. With a greater degree of steam admission the weakness of the boiler was felt. In the front truck of this locomotive sector supports were used as centering devices. The excellent operation of the front truck served much to popularize sector supports not only in our country, but also abroad. They were invented by A. Ye. Delacroa, and they were already in use on the front truck of the N^V locomotive. U locomotives were also in service on other roads, including the Nikolayevskiy and the Tashkent.

In 1911 on orders from the Ryazan-Ural Railroad the Putilovskiy Plant installed a superheater in the U locomotive. The new version was designated series U^u , (figure 60). This locomotive, as was pointed out above, did not live up to expectations, having lost the speed inherent in the U locomotive. Its operation was economically only at low speeds of 50 to 60 kilometers per hour. For such speeds the building of a complex four-cylinder compound engine with crank-shaft could not be justified. Weighing the same as the 1-3-1 S locomotives, the U^u locomotives were almost one-third inferior in power to the S locomotives at high speeds.

The U^u locomotives gained no further acceptance.

The Putilovskiy and the Khar'kov Plants worked out along the lines of the U^u locomotive more powerful 2-3-0 U^{uu} passenger locomotives for the Moscow-Vindava-Rybinsk Railroad, and for other roads. However, these projects were put into execution.

One of the 2-3-0 U locomotives on 23 January 1924 pulled the train with the body of Vladimir Il'ich Lenin from the Gerasimovo station of the Ryazan-Ural Railroad to Moscow. This locomotive ended its service in a museum in Moscow.

The characteristics of the U locomotives are given in table 25. [See table 25 on following page]

22. 1-3-1 S LOCOMOTIVE

The Commission of Rolling Stock and Locomotives under the chairmanship of N. L. Shchukin on 12 March 1911 had a meeting on a train of the Nikolayevskiy Railroad during a trial run of the 1-3-1 S

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TABLE 25. CHARACTERISTICS OF 2-3-0 U LOCOMOTIVES

Series	Cylinder diameter in mm		Stroke in mm	Driving wheel diameter in mm	Pressure in atmospheres	Heating surface in sq. meters		Grate area in sq. meters	Weight in tons	
	High pressure	Low pressure				Evaporating	Superheating		On drivers	In working order
U	2x370	2x580	650	1730	14	182	--	2.6	45	71
U[u]	2x410	2x580	650	1730	14	153	39	2.8	49	76

locomotive. The Commission, on the motion of its chairman, who drew the attention of the Commission to the favorable results of the trial run of this locomotive, and also to the excellent manner in which this locomotive was built and the thoughtfulness with which its separate units were designed and made, expressed its gratitude to the builders of the locomotive: B. S. Malakhovskiy, S. I, Mikhin, and G. Sokolov, who had labored mightily to create this type of locomotive. Such was the evaluation which this locomotive received after its very first run. Subsequent experience fully justified the high evaluation given it by N. L. Shchukin. The S locomotives, undoubtedly, were the best passenger locomotives built in Russia before the October Revolution. They received the widest recognition, and they were produced by four plants: Sormovo, Nevsky, Lugansk, and Khar'kov.

Many advanced ideas which were subsequently tested and proved in practical operation found their first application in the design of this locomotive. For instance, the spring suspension, divided into three independent groups, represents a system capable of being statically determinate. The steam chests are most efficient, the ratio of the volume of the steam chest to the useful volume of cylinder being 0.354, the maximum value in locomotives of our production. In other locomotives of old series this value was between 0.2 and 0.14.

Because of the well designed steam-distribution, the use of rhombic steam ports in steam chest bushing, and the successfully executed exhaust system, the S locomotives were remarkable in their exceptionally smooth motion at high speeds, being inferior [redacted]

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in speeds only to the Soviet-produced 1-4-2 IS and 2-3-2 locomotives of the Kolomna and the Voroshilovgrad plants. (The change of steam parts in the E. LP, S^u and SO locomotives to the triangular shape must be considered mistake, for in this case the working area of the steam ports was reduced approximately 20 percent. In all locomotives of more modern design; including the IS, FD, 2-3-2 L, and others, only rhombic ports are used.)

For the first time the axle journals had no beads on the ends, which make the production of axles more difficult and complicate the disassembly of the journal boxes in overhaul. The exhaust nozzle and smokestack system was designed on the principle of maximum development and utilization of the area of contact of steam and gases, doing away with the petticoat pipe, which is not used on modern locomotives. With the S locomotive there originated many parts and units which at present are considered to be standard or regular, such as the two-valve throttle with a mechanism, a firedoor, certain boiler fixtures, and so forth. In respect to convenience of inspection, maintenance, and overhaul the S locomotives are considered to be almost faultless.

While the 2-3-0 type was being evolved gradually and in the S and S^u locomotives, which were logical culminations of this development, numerous parts, tested by long experience were being installed, and the 1-3-1 locomotive was completely rebuilt, a development requiring from the designers solutions of much more complex problems. Nevertheless, so much thinking went into the design that in subsequent mass production, it did not have to be altered to any appreciable extent. The simplicity of the parts made a short building period possible.

We consider that it is necessary to remind the people about these achievements of Russian technical thought of the recent past, because they are either altogether forgotten, or people express ideas concerning them which are not in keeping with reality. For instance, a well known fact is sometimes cited, the fact that the model in the process of designing of Su Soviet locomotive was not the S locomotive itself, but its varient the S^v locomotive (figure 62), and by way of explanation it is said that the S^v was designed because certain defects of the S were revealed in operation. (F. P. Kononov, S^u "Locomotives" 1935, page 9-10. An absolutely wrong treatment of this question is given in Mokrshitskiy's book "History of Locomotive Building in the USSR," page 149) Listed among such defects is the allegedly unsatisfactory passage of the locomotive on curves, for which reason, in the opinion of the authors of this version, it was decided to equip the S^v locomotive with a rear truck and not with a rigid supporting wheel pair, as on the S locomotive.

However, anybody who was well acquainted with the actual designing and building of both locomotives, would not let himself be thus misinformed. The S^v locomotive was designed for the Warsaw-Vienna Railroad, with a 1435-millimeter gauge and low permissible clearances for the rolling stock. Under such conditions, in order to preserve the same boiler as for the S locomotive it was necessary to locate it at a height of 2900 millimeters above the rails, that is, 150 millimeters lower than on the S locomotive. In order to make room for the firebox and cinder box it was necessary to set the axle of the rear supporting pair to the rear, at the distance of 3100 millimeters from the axle of the last pair of coupled wheels, while this distance in the S locomotive was equal to 2200 millimeters. This meant that the wheel base of the S^v locomotive was 900 millimeters longer than the wheel base of the S locomotive. This consideration forced the Kolomna plant to utilize the rear truck to enable the locomotive to negotiate the curves of the smallest possible radius. Such is the true story of the appearance of the rear truck on the S^v locomotive.

The placing of the supporting pair of wheels to the rear, especially the pair that was not equalized with the rest of spring suspension, made the action of the S locomotive upon the roadbed more pronounced instead of bettering it, as was wrongly claimed in the press.

The truck designed by the Kolomna Plant, used in the S^v and subsequently in the Su locomotive under actual operating conditions proved to be more complicated and inferior to the truck of the S locomotive. On the basis of experience of many years, this can now be said with full assurance. The truck of the Su locomotive, and consequently of the S^v locomotive, requires more accurate and precise assembly, because it developed cutting and cross wear of flanges more often than the truck of the S locomotive. The shortening of the rigid wheel base in the S^v and S^u locomotives to 1?25 millimeters, as opposed to the 4200 millimeters of the S locomotives, although it facilitated the passage of the locomotive on curves, contributed to certain weaving motion, especially at high speeds.

The spring suspension system, which is statically determinate and with which loads on wheel pairs are not dependent upon the regulation of spring tension, was replaced in the S^v locomotive with a statically indeterminate system, in other words, it became worse.

The S^v locomotive proved to be more than one ton heavier than the S locomotive, at a time when considerations of weight played a very important role in the design of both locomotives.

When the S^u locomotive was in the process of designing, the S^v locomotive was taken as a model, not because it was better than the S locomotive, but because it lent itself better to redesigning having been equipped with the rear truck, which was absolutely necessary for the S^u and which only needed lengthening.

The steam distribution of the S locomotive, which has practically the same cross-section as in the S^v locomotive, and consequently in the S^u locomotive, with smaller cylinders works better. Furthermore, in the S locomotive the maximum degree of admission is 80 percent, while in the S^v and S^u it is only 70 percent. Because of this the S locomotive starts better. The absolute values of specific steam consumption are lower in the S^u locomotive than in the S because of higher superheating. But the minimum consumption of the S^u locomotive was obtained at 80 kilometers per hour, while on the S locomotive it was obtained at 120 kilometers per hour. Both locomotives develop maximum power at the same respective speeds. (table 33). This indicates that the S^u locomotive is better adapted for heavy passenger service, and the S locomotive for lighter service, its engine being more for an express type of train than for an ordinary passenger train. Development of maximum power at the highest speed is also characteristic of the 2-3-2 express type of locomotive of the Kolomna plant.

What the values of these characteristics of the S^v locomotives were, we do not know, since these locomotives were not tested.

S^v locomotives to the number of 15 were built by the Kolomna Plant in 1914. The boilers of these locomotives, made by the Sormovo Plant, operated at a pressure of 12 absolute atmospheres, and they had seams, not of three rows as on the S locomotives (with a pressure of 13 atmospheres), but of two rows.

In tests of passenger locomotives on the Nikolayevskiy Railroad in 1913 the best of all the types of locomotives tested were the 1-3-1 S and 2-3-0 K^u locomotives. The advantages of the K^u locomotive were the well designed engine and in the presence of the two-axle truck. In boiler and the running gear the advantage lay with the S locomotive. In order to give the comparative evaluation of engines of both locomotives we cite here the final deductions, formulated on the basis of later study of the tests of 1913, which were published in 1925. ("Tests on the Nikolayevskiy Railroad, 1912-1914,", 1, 1925, page 377)

"At the most advantageous throttle settings at the speeds of about 120 kilometers per hour the S locomotive gives the consumption of normal steam per unit of crank power of about 9.1 kilograms per hour, while this consumption in the K^u locomotive equals about 9.6 kilograms per hour. In other words, of all the locomotives tested at very high speeds the most advantageous in the consumption of steam is the S locomotive." In the technical evaluation of the locomotives tested the following conclusion was drawn "Under very high speeds the engine of the Ku locomotive operates worse than the engine of the S locomotive, and this worsening grows with the cut-off" (ibid, page 420). Furthermore, to these conclusions it should be added that under identical speeds the Ku locomotive engine, working with a smaller number of revolutions (diameter of driving wheels of the Ku was 1900 millimeters, and of the S locomotive 1830) operated better. In addition, at first the S locomotive was equipped with a less satisfactory Notkin superheater. Hence it follows that had these engines been brought to identical operating conditions the superiority of the S locomotive engine would have been even more apparent. From table 33 it can be seen that the S locomotive develops the greater power at 120 kilometers per hour and the Ku locomotive at 80 kilometers per hour, so that the first locomotive is regarded as an express type, and the second as a passenger type (this has been already mentioned in the comparison of the S and the S^u locomotives).

In 1913 the S and Ku locomotives were scheduled for the eight-hour run between St. Petersburg and Moscow on the Nikolayevskiy Railroad. Because of its less powerful boiler and less sturdy construction the Ku locomotive could not stand the required speed. Overheating the journals led to a breakdown of the front truck axle during one of the runs. In 1913, as an experiment, several Ku locomotives were sent to the Warsaw line of the Northwestern Railroads, which at the time was noted for its fastest express and suburban trains with the average commercial speeds on individual stretches up to 85 kilometers per hour. This line was being serviced by S locomotives. The trains were among the fastest in Europe. The Ku locomotives, in spite of the fact that they were

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fueled with high-quality fuel, operated under maximum pressures and stresses, but still could not keep up with the time table of the Warsaw line.

The Warsaw line of the Northwestern Railroads was the first road to get S locomotives. They were obtained on the initiative of Professor I. A. Stazharov, who at the time was the head of the Technical Division of the Locomotive Service of the railroad.

The locomotives were procured first of all to speed up the suburban traffic. The express train runs were also speeded up. For instance, the express train covered the distance of 94 kilometers between Gatchina and Luga with stops at both stations in 67 minutes, according to the time table, with an average speed of 85 kilometers per hour, and a maximum speed of 110 kilometers per hour. (see the Official Railway Communications Guide for 1911). Until 1911 express trains with N^{V} locomotives travelled from St. Petersburg to Luga (138 kilometers) in 3 hours, and after 1911 with S locomotives in 1 hour 50 minutes.

N. L. Shchukin constantly fought for higher speeds on the Russian railroads. Technically such speeds became possible with the production of the S locomotives, which fully met the requirements of the period. As a partisan of these locomotives, N. L. Shchukin was responsible for their widest acceptance by the state-owned roads. These locomotives made it possible to increase passenger train speeds greatly from 1912 to 1913. Of the private roads only the Severo-Donetskiy ordered these locomotives.

On the initiative of N. L. Shchukin and under his direction experimental runs of "lightning" trains between St. Petersburg and Moscow were organized. On 6 December 1913 a train consisting of nine cars made a record run (for that time) of 7 hours 59 minutes, or, subtracting time for stops, of 7 hours 30 minutes. In spite of the blizzard that was encountered on the road, the train at times developed the speed of 117 versts (125 kilometers) per hour. In the opinion of N. L. Shchukin, which he expressed after he had returned from this brilliant trip, under more favorable conditions the distance of 650 kilometers between the two capitals could be covered in 7 hours. For the next year, 1914, a trip of 6 hours with one stop at Bologoye was planned.

For this reason the Sormovo plant received an order for two S locomotives with large connecting-rod oilers (this information was given to the author by B. S. Malakhovskiy, the designer of the S locomotive). The war, which began in 1914, interfered with the implementation of N. L. Shchukin's plans.

At the end of October 1932 a fast express train experimental run was made from Leningrad to Moscow and back on the Oktyabr'skiy Railroad with the participation of Docent B. A. Pavlov and the author of this book. At that time 2-3-1 L^P locomotives were also in service on this road. The railroad selected S locomotives for this express train as the fastest and the most reliable at high speeds. Maximum speed on the return trip was shown by the S 277 locomotive, which covered the distance of two kilometers between Obukhovo and Farforovskiy Post in 58 seconds, developing a speed of 124 kilometers per hour.

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The run from Moscow to Leningrad with four stops was made in 8 hours, with an average speed of 100 kilometers per hour. On some stretches the speed was constantly kept within the range of 115-120 kilometers per hour.

Soviet locomotive-building technology has advanced immeasurably. Now we have the fast 2-3-2 locomotives of the Kolomna Plant which have developed 170 kilometers per hour, and 2-3-2 locomotives of the Voroshilovgrad Plant, which are designed for 180 kilometers per hour. These locomotives are worthy successors of the best locomotives of the recent past.

The characteristics of the S locomotives are given in table 26.

[Table 26 on following page]

23. 1-3-1 S^u LOCOMOTIVES

At present the S^u locomotives are the basic type of passenger locomotives on the railroads of the USSR.

By 1924 the inventory of freight locomotives had been considerably restored and replenished with the New E locomotives, production of which was planned to end in the following year.

It was not wise to discontinue locomotive building which was already organized in the country, and, therefore, the representatives of the industry insisted on immediate transition to the building of passenger trains of approximately the same power, especially since there was a shortage of locomotives in service.

TABLE 26. CHARACTERISTICS OF THE 1-3-1 S LOCOMOTIVES

Series	Cylinder diameter in mm	Stroke in mm	Driving wheel diameter in mm	Pressure in atmospheres	Heating surface in sq. meters: Evaporated	Heating surface in sq. meters: Superheated	Grate area in sq. meters	Weight in tons: On drivers	Weight in tons: In working order
S	550	700	1830	13	207	52	3.8	47	76
S^{v}	575	700	1850	12	207	52	3.8	48	77

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By that time S locomotives already ceased to satisfy increased requirements and the resumption of their building was out of question. The only more powerful type at the time was the 2-3-1 IP locomotive, but its operation and tractive qualities were not as yet ascertained, and the type per se, because it was adapted only for fueling with oil and did not satisfy conditions for basic service in mass transport. Moreover, technical facilities of the majority of the plants could not be employed in the production of such complex locomotives. Because of it only a few of these locomotives were ordered from the Putilovskiy Plant.

The design of a new more powerful passenger 2-4-0 locomotive at the time was far from being complete, and, besides, this locomotive in its complexity was almost on a par with the 2-3-1 type. Therefore, even if the design had been completed, serial production of this locomotive could not be effected for several years to come.

Consequently only the 1-3-1 type remained as the one the production of which could be carried out by our plants, and it was decided to build this type but with alterations and improvements. As it was pointed out before, the most adaptable locomotive for this redesign was not the locomotive of the original S series, but its variant -- the S^V which required fewer changes and which permitted redesigning in a shorter period of time. The changes, through which the SV locomotive was made into Su , were the following:

the firebox was lengthened almost by 700 millimeters, but its original width was kept the same;

grate area was increased from 3.8 to 4.73 square meters;

the smoke box was lengthened by 500 millimeters;

number of flues was increased from 24 to 32, and of tubes decreased from 170 to 135;

boiler pressure was increased from 12 to 13 atmospheres;

rear supporting wheel pair, because of lengthening of the firebox was moved back 300 millimeters;

the axis of the boiler was raised from 2900 millimeters above the level of the rails to 3200 millimeters; driving gear was reinforced because of the increase in boiler pressure;

feed water heater of surface type was installed.

As a result of all these changes in design the weight of the locomotive was increased almost by 7 tons, and the load of a driving wheel pair upon the rails was increased from 16.25 to 17.9 tons.

The design of the S^u locomotive was looked upon as merely an alteration of the S^v locomotive. But, considering the number of changes and their natures, it must be acknowledged that this was a new design. Therefore, the S^u locomotive is recognized as the first passenger locomotive of Soviet construction (Figure 63). Elaborasion of the design and building of the first locomotives were carried out at the Kolomna Plant under the direction of K.N. Sushkin. In 1925 production of S^u locomotives was started by the Kolomna, Sormovo, Lugansk, Bryansk, and Khar'kov plants. These locomotives were identified as the S^u-96 series.

When the first locomotives were weighted it was established, however, that the load of the rear supporting wheel pair considerably exceeded the load provided for by the design, reaching in some locomotives 19 tons. These locomotives were identified as the S^{ut} series (S^u heavy).

To reduce the weight and decrease the load of the rear supporting wheel pair the designs were reexamined, and some cast frame attaching bars were replaced with forged bars. The boiler was moved forward 175 millimeters which necessitated further raising of its axis by additional 130 millimeters. The position of the lower part of outside throat sheet called for a change in position of springs of rear supporting and the driving wheel pairs which were moved down. The S^u locomotives altered in this manner composed the main part of the first production, were known as 1926 type and were in production until 1919. Their series numeration was from 97 to 101.

Production of the S^u locomotives was resumed only in 1932. The blueprints again were reworked in order to eliminate those defects which were revealed in locomotives of the first series.

Changes in design were also caused by introduction of welding, economy in the use of nonferrous metals, use of standard parts, etc.

The main point of difference in boilers of the second series of S^u locomotives was in the firebox. The riveted copper outside sheet was replaced with a steel one with the use of welding and flexible stay-bolts. The upper part of the throat sheet because of formation of cracks in its fold was straightened out, and because of it the diameter of the tube part of the boiler was increased by 60 millimeters. The smokestack was made simpler, and the front firebox door was also altered. All this considerably changed the general appearance of the locomotive. The tender was also considerably redesigned. The series numeration of these locomotives was from 200 to 209 (Figure 64).

S^u locomotives built since 1935 and known as S^u of the third series, again were somewhat redesigned. The firebox was equipped with

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three circulator pipes and a light firebrick arch supported by the circulator pipes. The cinderbox was of bunker type with air admitted on top. The coupling bar was designed so that it could be used with automatic coupling without friction mechanism. Cylinders seals were replaced with a system which fully justified itself in IS locomotives. Guides were reinforced and a center bolt was added to secure a guide to the guide bar. Furthermore, the camshaft was changed.

For convenience of the train crew the cab was redesigned and and upper light for the cab was added, the locomotive and the tender were bridged, etc. This series of locomotives is numbered from 210 to 215. Some of these locomotives in 1937-1940 were built with airheater in the firebox.

In 1938 it was decided to test fan draft on locomotives fueled with oil. S^u locomotives fueled with oil, built in that year for the North-Caucasian railroads, were, at the suggestion of the Kolomna Plant, equipped with fan draft. The idea was to test the blades of smoke blower under oil fueling conditions. With the permission of the Locomotive Administration of the NKPS the Kolomna Plant built several such experimental locomotives.

Because shortly after this there was a cutting down on the number of locomotives built for oil fueling, the S^u locomotives which were originally supposed to be fueled with oil, were changed while under construction to coal fueling and were delivered to the Moscow roundhouse of the Oktyabr'skiy Railroad. They were identified as S^{um} series (Figure 65); their series numbers are from 216 to 218. Operating on coal with fan draft on the Moscow-Bologoye division, side by side with the S^u locomotives with exhaust nozzle draft, the

S^{um} locomotives showed a sharp increase in boiler steam generating capacity, especially with coal of inferior quality.

Successful results with fan draft were also simultaneously obtained with SO locomotives without steam condensation, which were identified as SO^{18} series. Good steam generation of S^{um} and SO^{18} locomotives equipped with fan draft was especially important during the Great Patriotic War, when quite often locomotives had to be fueled with coal of most inferior quality.

Furthermore, S^{um} locomotives were equipped with steam air heaters and feed water heaters of surface type. The latter, because of their poor operation, were not installed on locomotives of the last series. S^{um} locomotives were also equipped with smoke deflecting shields.

The S^{u} locomotives which are built now by the Krasnoye Sormovo Plant imeni A.A. Zhdanov have the series number 250. They are built with improved superheaters and with 40 flues. The first postwar S^{u} locomotive was delivered by the plant in August 1947. On the proposal of Chief Engineer of the Central Locomotive Administration of the Ministry of Communications, A.A. Ivanov, the steam distribution system was redesigned. With a slight lengthening of the link the advancing mechanism was altered which resulted in a slight decrease in the maximum admission, but on the other hand increased passage section under operational admissions. This design was elaborated at the Krasnoye Sormovo Plant under the direction of A.M. Rusak. Other parts of locomotive were also changed. Water is fed into the steam space. The steam dome was moved to the second course of the tube part of the boiler. The wheels of the front auxiliary pair are disc.

Tests of S^u locomotive, series 97, were conducted in 1927 on the Oktyabr'skiy railroad under the direction of V.F. Yegorchenko, O.N. Isaakyan, and R.P. Grinenkol.

For these tests the Kolomna Plant prepared the S^u 97-12 locomotive, all the necessary calibrations were done and steam distribution system was checked.

Tests demonstrated exceptional operational economy of the S^u locomotive. In operation on fuel oil general efficiency was 9.9 percent with the speed of 80 kilometers per hour. The locomotive proved to be not only the most economical in the USSR, but also one of the most economical in the world. It is especially adapted for heavy passenger service under speeds of 60-80 kilometers per hour and it is suitable for coal fuel.

Test research on the S^{um} locomotive was conducted in 1940 on the Levoshenko-Spirovo stretch of the Oktyabr'skiy Railroad under the direction of Docent Candidate of Technical Sciences, P.A. Gurskiy. This research established that the efficiency of the S^{um} locomotive was slightly less than the efficiency of the S^u 97 locomotive. This was caused first by the increased resistance of the superheater pipes to passage of steam, because Chusov's pipes were replaced by the four flue two cycle system, the total steam passage area of which was decreased by 16 percent. Secondly by the increase of the counterpressure on the non-operating side of the piston, this counterpressure amounted to 1 absolute atmosphere and even above. This was caused by the use of fan draft, taken without any changes in design from the SO locomotive, with steam condensation. In this case the fan draft had excessive power for this locomotive. Furthermore, joining of three exhaust pipes into one common T created a backpressure of steam exhausted from one cylinder against the exhaust of another cylinder. Thus, the use of fan draft in the S^{um} locomotive somewhat detracted from the operation of the engine. But operation of the boiler was improved.

In 1936 on the initiative of Engineer of Oktyabr'skiy railroad N.I. Patlykh the steam distribution system of the S^u locomotive was altered through an addition of an accelerator. Under operating admissions of steam, passage sections were increased by 20-30 percent and maximum admission was brought up to 80 percent. Locomotives with steam distribution systems redesigned in this manner exhibited better start, faster acceleration and a certain saving in fuel consumption.

On 17 November 1936 S^u 204-71 locomotive equipped with redesigned steam distribution system and accelerator system of Engineer N.I. Patlykh made a test run with an express train from Leningrad to Moscow with return trip on 19 November. The train of five cars, including one dynamometric car, made the return trip in 6 hours 20 minutes, with an average speed of 100 kilometers per hour, and maximum speed of 125 kilometers per hours. The run was made under the direction of Engineer N.N. Markov with the participation of N.I. Patlykh, B.A. Pavlov and the author of this book. It is known that S^u locomotives with an ordinary steam distribution system are not capable of such high speeds. While passing at a speed of 125 miles per hour through the switches at the station Vyshniy Volochek, no shocks were registered in the dynamometric car — shocks which usually accompany when passing through switches at lesser speeds. Evidently, each individual shock lasted such a short time that it resulted in a very weak impulse which could not transmit vertical acceleration to the ear.

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Characteristics of S^u locomotives are given in Table 27.

See Table 27 on following page

24. 2-3-1 L^P LOCOMOTIVES

By 1914 the average weight of passenger trains on the Vladikavkaz Railroad reached 600 tons. With heavy profile of the road and water of inferior quality the road needed passenger locomotives of great power. The railroad estimated that none of the then existing types of passenger locomotives could satisfy the requirements.

The railroad selected the locomotive of 2-3-1 type. The rough draft of the design was prepared by V.I. Lopushinskiy, and its development was carried out by the Putilovskiy plant in the person of A.S. Rayevskiy in consultation with M.V. Gololobov. The first 2-3-1 locomotive, which was identified then as L series, and later as L^P series, was built in April 1915 (Figure 67).

The locomotive had a four cylinder engine of single expansion. In an explanatory note accompanying the design of the 2-3-1 L^P locomotive it was stated that "one of the most difficult and specific questions is the following: should the locomotive be built with a four cylinder compound engine operating on superheated steam at a pressure of 14-16 atmospheres, or should it be of a simple system with 12 atmosphere pressure of superheated steam (page 5)". It is known that the Vladikavkaz railroad selected the second alternative. Compounding was given up for the sake of possible aimplification of construction, reduction in weight of boiler and cylinders, reduction of steam pressure, better balancing at various steam admissions, and, finally, greater starting tractive force. This was one of the fun-

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TABLE 27

CHARACTERISTICS OF 1-3-1 S^u LOCOMOTIVES

Series	Cylinder Diameter in mm	Stroke in Millimeters	Driver Diameter in mm	Pressure in Atmospheres	Heating Surface in Square Meters		Grate Area in Square Meters	Weight in Tons	
					Evaporating	Superheating		On drivers	In working order
S^u 96	575	700	1850	13	197	73	4.73	54	86
S^u 97	575	700	1850	13	197	73	4.73	54	84
S^u 200	575	700	1850	13	197	72	4.73	55	85
S^u 210	575	700	1850	13	199	72	4.73	55	85
S^{UM}	575	700	1850	13	199	72	4.73	55	85
S^U 250	575	700	1850	13	188	89	4.73	55	85
S^{UR}	575	700	1850	13	188	89	4.73	55	86

damental errors on the part of the Vladikavkaz railroad. Since the engine had been already made complicated by inside cylinders and crankshaft, it would have been sensible to employ the principle of compounding which gives a certain economy in fuel consumption even with superheating and which would not have introduced any further essential complications. This point of view in the past was defended by A.S. Rayevskiy and A.O. Chechott, and, of course, they were quite right.

With the idea of better balancing of dynamic loads transmitted by wheels upon the rails, reduction in stresses upon the middle coupling crank-pin, and also for reduction in length and of weight of inside connecting rods, the action of inside and outside cylinders is distributed in these locomotives upon the two driving wheel pairs, of which the last one has a crankshaft. To reduce vertical reaction of the force of steam, the engines have horizontal cylinders set with a displacement along the axle of 75 millimeters. This permitted to bring up the static load of driving wheel pairs to 17.3 tons. At the subsequent weighing on the scales of the Proletarskiy Plant during the 1931 tests of the I^{P} 154 locomotive, conducted by the author of the book, the real load reached 20 tons.

Very good balancing was achieved in Ip locomotives. But the boiler, which was designed, as ordered, for oil fuel only, does not have adequate firebox for sufficient power, which fact was already noted above. Spring suspension, with five individual groups, is statically indeterminate. The engine has straight streamlined steam passages with well developed inlet and exhaust systems.

Because of the difference in length of connecting rods of out-

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side and inside engines, and of considerable displacement along the axis, dead settings of outside and inside engines, the cranks of which are set on 180 degree angle, do not coincide considerably in their moments. Motion is transmitted to outside and inside valves from outside lines, in case of inside valves — through horizontal levers with equal shoulders. To achieve the greatest uniformity of admissions a bent pendulum is used, the upper shoulder of which is bent to the rear 40 millimeters. The range of line admission-leads at the change of admission values reached almost 2 millimeters.

Under operating conditions Lp locomotives did not exhibit economy of fuel. Their specific steam consumption was considerably higher than that of the S locomotives, and, especially, of the Su locomotive, which fact has been already discussed. In describing the results of the first trial run of the new Lp 101 locomotive immediately after its delivery from Petrograd to Okulovka and return on the Nikolayevskiy railroad, conducted on 30 April 1915, Professor A.O. Chechott wrote: "Average evaporation of oil for the run was altogether about 7 kilograms, i.e., it must be recognized as very mediocre, steam generation was not sufficient, steam was maintained at the normal pressure only for a short period, and then it would fall to 8.5 absolute atmospheres. Admission was mostly 40 to 50 percent, which with single expansion was very high, but superheating was quite satisfactory and at times high, reaching 400 degrees. The train weighted 532 tons. Maximum speed was 110 versts (117 kilometers per hour)." (A.O. Chechott, More about the Vladikavkaz Pacific.)

Lp locomotives of the first series from number 101 to 118 were built by the Putilovskiy Plant in the period from 1915 to 1918, and they went into service on the Vladikavkaza Railroad. The second series from number 119 to 166 were built from 1924 to 1926 and they were delivered to the Oktyabr'skiy railroad. The same road also received locomotives of the first series from the Vladikavkaz Railroad. Thus all 6 locomotives were concentrated on the Oktyabr'skiy railroad, in the service of which they were from 1924 to 1936, being eventually replaced by the Su locomotives. (The Lp 107 locomotive wrecked in a collision in 1920 near Novorossiysk was not sent to the Oktyabr'skiy Railroad.)

They did not develop any further, notable increase in speed, which was expected of them after they had been moved on the level track of the Oktyabr'skiy railroad. And when oil burning Lp locomotives were replaced by coal burning Su locomotives, the weight of trains and speeds were left unchanged.

Being operated for a time under the same conditions as Su locomotives the Lp locomotives could be easily compared with the first in fuel consumption and other features. Pulling fast trains from Leningrad to Bologoye (320 kilometers) the Su locomotives consumed in a single trip 2.9-3 tons of oil, while the Lp locomotives consumed 3.9-4 tons. The cost of repairs of the same mileage unit for Lp locomotives was 2.5 times higher than for the Su locomotive. In addition, much trouble was caused to the road by the Lp locomotives, because of frequent appearance of cracks in the bends of crankshafts. Short service of crankshafts was explained by very high stresses at the places of profile changes. Red Putilovets Plant, working on other orders, could not supply the necessary quantity of spare crankshafts which were needed to replace the cracked ones. And importing them from abroad cost thousands of gold rubles per crankshaft. The crankshaft lasted on the average for a run of 100-150 thousand kilometers.

At a very rough estimate the replacement of Lp locomotives by the Su locomotives resulted in saving to the road of at least one million rubles per year. Such were the conclusions from operational experience. (Operation of the Lp locomotives on the Oktyabr'skiy Railroad confirmed the deductions concerning operation of these locomotives on the Vladikavkaz railroad which were made by S.A. Bogdanov and which were reported by him to the 23rd Consultive Congress of the member of Locomotive Service in 1923 (page 149).)

Tests of Lp 141 locomotives were conducted in the summer of 1926 on the Oktyabr'skiy railroad between Bologoye and Kalinin under the direction of R.P. Grinenko, V.F. Yegorchenko, and O.N. Isaakyan.

One ons of the test trips, in which the author of this book took part, a train weighing 2300 tons and consisting of 46 four axle cars, of which half the number were freight cars, was coupled to the test Lp 141 locomotive. The start was made with the help of a pusher Shch[ch] locomotive. The train traveled from Bologoye to Kalinin at a speed of 60-70 kilometers per hour. Dynamometric traction force ranged from 6000 to 7000 kilograms. This gave mean effective power of 1700-1800 horse power.

Comparison of the Lp with the Su locomotive on the basis of the results of these tests indicated that the Su as a thermic prime mover was more economical than the Lp locomotive on the average by 30 percent.

On one of the Lp locomotives, as an experiment, cylinders were reduced in diameter from 460 to 420 millimeters. No noticeable results were observed.

From 1927 to 1929 almost all Lp locomotives were equipped with water heaters of mixture type, built by the Red Putilovets Plant. Because of unsatisfactory operation, they were soon taken off.

In 1914 a design of 2-3-1 locomotive was also prepared at the Sormovo Plant by B.S. Malakhovskiy. The design was further developed together with the design of 1-4-1 passenger locomotive, and boilers, cylinders and some other parts of the two locomotives were made interchangeable. The Sormovo Plant design of the 2-3-1 locomotive provided for a two cylinder engine and a larger firebox than on the Lp locomotive. For maximum development of steam passages Sormovo designs of 2-3-1 and 1-4-1 locomotives provided for the use of valves of 350 millimeters in diameter. It was also planned to use on the 2-3-1 locomotive a device to improve traction, permit increasing the weight on drivers at the moment of start by 7 tons. The war of 1914-1918 interfered with the implementation of these projects.

Characteristics of the Lp locomotives are given in Table 28.

See Table 28 on following page

25. 1-2-0 ≠ 0-2-0 i and 1-4-0 I LOCOMOTIVES

Passenger locomotives with four coupled wheel pairs first appeared on our railroads in 1903. Then the Kolomna Plant built for the Middle Siberian Railroad nine locomotives of articulated type with compound engine. They were identified as i series. The change to four coupled wheel pairs was caused by the weakness of the upper part of the roadbed and of bridges which did not permit the load of

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TABLE 28

CHARACTERISTICS OF 2-3-1 L^P LOCOMOTIVES

Series	Cylinder diameter in mm	Stroke in mm	Driver diameter in mm	Pressure in atmospheres	Heating surface in square meters		Grate area in sq. meters	On drivers	In working order
					Evaporating	Superheating			
L^P	4x460	650	1840	12	271	86.5	4.65	52	97
L^PNo 119	4x420	650	1840	12	271	85.5	4.65	52	97
2-3-1 (as designed by the Sormovo Plant)	2x650	700	2000	13	263	93	5.0	50/57[1]	92.5

1 Second value with traction increases.

a wheel pair upon the rails of over 10 tons. These locomotives operated satisfactorily with passenger trains, but their fuel consumption was considerable (Figure 68).

After this, building of passenger locomotives with four coupled wheel pairs was discontinued until 1909. By that time increased passenger traffic on the Moscow-Kazan' Railroad, brought about by the construction of the new Lubertsy-Kazan' line, demanded locomotives with the same tractive force as developed by the 2-3-0 locomotives, but with the load of a wheel pair upon the rails no more than 14 tons. The Moscow-Kazan' railroad selected the 1-4-0 type, which was designated I series. These locomotives were fairly successful in design and fuel consumption (Figure 69).

Their boilers and engines are the same as those of the 0-4-0 V locomotives. Some I locomotives were equipped with water pipe fireboxes, in which sidewalls were formed by a row of vertical pipes set in such manner that they pressed against each other.

In this locomotive the Kolomna plant used for the first time that type of truck which later was used first on Sv and later on the Su locomotives. The radius bar pin, around which turns the radius bar of the front leading wheel pair, is located infront of another king pin around which turns the horizontal equalizer. In Sv and Su locomotives the front king pin is the equalizer pin. This position of pins is dependent upon the length of the radius bar.

Characteristics if i and I locomotives are given in Table 29.

See Table 29 on following page.

TABLE 29

CHARACTERISTICS OF 1-2-0+0-2-0 i and 1-4-0 I LOCOMOTIVES

Series	Cylinder diameter in mm		Stroke in mm	Driver diameter in mm	Pressure in atmospheres	Heating surface in sq. meters		Grate area in sq. meters	Weight in tons	
	High pressure	Low pressure				Evaporating	Superheating		On drivers	In working order
i	2x420	2x630	600	1350	12	186	-	2.6	52	64
I	575	-	650	1500	12	163	47	3.03	55.6	69

26. 2-4-0 M[F] LOCOMOTIVES

At the end of restoration period (1922-1923) in the Soviet Union a great increase in passenger traffic was expected, and the question of selecting a type of locomotive for use in the immediate future came to a head.

Among the specialists of that period there was a considerable number in favor of the use on our road of complex locomotives with crankshafts. In their opinion, giving up the idea of such locomotives was tantamount to giving up all progress in locomotive building.

The first part of the program consisted of the resumption of building of 2-3-1 Lp locomotives. Simultaneously, in 1923 the preparation of a design of a new powerful three cylinder 2-4-0 M locomotive was begun under the direction of A.S. Rayevskiy.

This design was supposed to contain several absolutely new, at the time, features, for instance, combustion chamber, which up to that time was never used in Russia, shifting part of the locomotive's weight to the tender, unique construction of the connecting rod of the inside engine, which with the horizontally mounted cylinder would permit to place the crankshaft back of the axles of front coupled wheel pairs, etc.

For the first time in the world A.S. Rayevskiy proposed an original arrangement of driving mechanism of the three cylinder locomotive in which with the 120 degree setting of driving cranks, the pins of coupling rods were to be set in wheel cranks at a 90 degree angle as in two cylinder locomotives. But the design provided crankpins for the driving wheel pair. This was supposed to decrease the loads on coupling rods, which under the usual for three-cylinder lo-

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comotives, setting of outside cranks at a 120 degree angle, rapidly loosened, which was one of the most important defects of three-cylinder locomotives.

After A.S. Rayevskiy's death in 1924 several simplifications were introduced into the design of the M locomotive. The whole design was completely redesigned, and several features which were proposed by Rayevskiy were not used.

In 1927 the first M locomotive was built on the new design. M locomotives were built by the Red Putilovets and Lugansk plants. M locomotives had several important defects of which the most essential one was in a considerable incline of the inside cylinder axis with de-axial engine. Because of increased vertical forces derived from the force of steam and rapidly growing uneven wear of the driving wheel-pair as compared with coupled wheel-pairs, destructive effect of the locomotive upon the track has increased.

Frequent loosening of coupling roads was observed; this could have been prevented through Rayevskiy's proposal. In addition, M locomotives frequently suffered from wheel slipping, uneven motion, side rocking and general roughness which caused severe hammering of the boiler against the frame. Moreover, the depeth of the firebox and the dimensions of the cinder box did not correspond to the quality of coal used in the USSR and they were not adequate.

A considerable improvement of these locomotives was achieved by their conversion to two cylinder locomotives (Mr series). In the remodelings the crankshaft of the second driving pair was replaced with a straight axle and the third cylinder was taken off. To maintain sufficient cylinder tractive force steam pressure was raised from 13 to 14.5 atmospheres. Wheel centers were left as before with proper rearrangement on axles.

M^{r} locomotives had no more wheel slippage, unevenness of wear of wheels decreased, motion became less rough, and steam generation improved.

Operating on the Ryazan'-Ural Railroad on the same timetable as M locomotives which have not been altered, the M^{r} locomotives pulled the same trains with smaller consumption of fuel.

It should be remembered that even during the First World War B.S. Malakhovskiy, working at the Sormovo Plant, designed a passenger locomotive of 1-4-1 type with a two cylinder engine. However, the war put a stop to the implementation of this project. As it was mentioned before, the most important assemblies and parts of the 1-4-1 type were made interchangeable with corresponding parts of the 2-3-1 type. After its failure with the M locomotive, the Kolomna plant also worked out a technical design of a 1-4-1 locomotive with wheel diameter of 1700 millimeters and grate area of 6 square meters. However, this project was not implemented, because by 1930 the need of a change to more powerful locomotives of IS and FD types was already strongly felt.

See Table 30 on following page.

27. 1-4-2 IS LOCOMOTIVE

Building of IS locomotives was begun in 1932. This type of locomotive is one of the best passenger locomotives of the USSR.

In February 1932 using a rough draft of a special technical

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TABLE 30

CHARACTERISTICS OF 2-4-0 M LOCOMOTIVES

Series	Cylinder diameter in mm	Stroke in mm	Driver diameter in mm	Pressure in atmospheres	Heating surface in square meters		Grate area in sq. meters	Weight in tons	
					Evaporating	Superheating		On drivers	In working order
M (A.S. Rayovskiy's design)	3x575	700	1700	13	253	99	6.0	72	98
M	3x540	700	1720	13	260	88	6.0	69.5	99.5
M^{r}	2x540	700	1720	14.5	260	88	6.0	69	99
1-4-1 Sormovo design of 1915	2x650	700	18300	13	263	93	5.0	63	92

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bureau the Office of Locomotive Design of the NKTP (TsLPB) started on the detailed development of a design of a powerful 1-4-2 locomotive which was built by the Kolomna Plant in collaboration with the Izhorsk Plant in October of the same year for the 15th anniversary of the October Socialist Revolution (Figure 71).

Under tests in individual cases the IS locomotive developed up to 3250 horsepower. In addition to great power this locomotive is also noted for high technical quality of its design.

Its principal units are interchangeable with corresponding units of the freight locomotive 1-5-1 FD. A considerable increase in heating surface, grate area, and total volume of firebox insures high steam-generation capacity of the boiler. The boiler has a combustion chamber, which contributes to better weight distribution and somewhat to the efficiency of the firebox. The superheater is of the flue with small pipes type. The five valve throttle is moved from the boilerand mounted behind the superheater. The stoker serves not only to make the work easier for the fireman, but also to obtain better steam generation. The exhaust steam pipe has four openings with partitioned exhaust which considerably lowers counterpressure at the exhaust and facilitates formation of gas and steam mixture. Steam cylinders are of cast steel with iron bushings. Cylinders, being connected with each other, form a block which serves as a front support for the boilerand for securing of frames in the front part. The guide is composed of three bars, thus reducing specific pressure. Main rods have solid ends turning on floating bushings lubricated with solid grease. The frame is of girder type of cast steel, having high transverse rigidity and lesser height over cut outs for journal boxes. Spring suspension is from above, it is of statically determinate system, under which the distribution of loads on axles does not depend on the tension of springs.

Tests conducted in 1933-34 indicated very economic operation of the IS locomotive engine, as a result of large straight steam passages, large — 330 millimeters — diameter of the valve, well developed exhaust system with 4 holes in the exhaust pipe and large openings of steam pores under operative admissions. The ratio of valve port closing to linear admission lead is 12. With this ratio the largest admission value is only 60 percent.

To facilitate starting, special steam admission ports of 4 x 40 millimeters are made in valve bushings. Through these ports steam enters the cylinder after the cut off. However, as subsequent experience has shown, such an arrangement requires the use of cylinders of large diameter which makes the driving gear heavier, and thus calls for sturdier construction.

This is a negative feature of the driving mechanism used in IS and FD locomotives.

Boiler operation turned out to be quite satisfactory. A certain inevitable flowering of its efficiency, caused by the use of mechanical stoker, is inherent in all locomotives with such fueling system because of the increase in mechanical carrying away of small particles into the smokebox.

On IS locomotives built after 1935 (also on the FD) Rachkov system stoker was installed. Rachkov also proposed to reduced the carrying away of fine coal particles by forming a steam curtain in the firebox. However, this device did not prove satisfactory.

The 1-4-2 type with specifications accepted for the IS locomotive should be considered as suitable for the majority of roads with heavy profile (curves and grades). So far as dynamics are concerned it is necessary to reexamine blancing in order to decrease jerking, and also to produce a well-worked out design of the front truck.

The IS locomotives in service on the Oktyabr'skiy railroad developed very high speeds, reaching in individual cases 140 kilometers per hour.

One of the IS locomotives, built by the Voroshilovgrad Plant, was equipped with streamlined shell and lightened driving gear. In 1934, an IS locomotive, representing Soviet locomotive building, was exhibited at the Paris World Fair.

Characteristics of the IS locomotive are given in Table 31.

See Table 31 on following page

28. 2-3-2 LOCOMOTIVES

The question of building a more powerful and faster locomotive with three couples wheel-pairs was raised as far back as 1934. Two ways of procedure were mapped: either to rework radically the Su, completely modernizing it, or to design absolutely new types. In 1934 the Kolomna Plant prepared rough drafts of designs of 2-3-1 locomotives with grate areas of 5 square meters, and of 1-3-2 and 2-3-2 locomotives with grate areas of 6.5 square meters. The last type, that is, the 2-3-2, as the one most deserving of attention, was a subject of lengthy discussion, and by 1935 its technical design was prepared. The wheel diameter was then set at 1850 ~~kilometers,~~ millimeters

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TABLE 31

CHARACTERISTICS OF THE 1-4-2 IS LOCOMOTIVE

Series	Cylinder Diameter in Millimeters	Stroke in Millimeters	Driver Diameter in Millimeters	Pressure in Atmospheres	Heating Surface in Square Meters		Grate Area in Square Meters	Weight in Tons	
					Evaporating	Superheating		On Drivers	In working order
IS	670	770	1850	15	295	139	7.03	80	134

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suitable for speeds of 120-130 kilometers per hour. The NKPS at first insisted on four coupled wheel pairs, but subsequently consented to three wheel pairs, on the condition that speed would be raised to 140 kilometers per hour.

The design was changed to a 2000 millimeter wheel diameter. After it had been examined at the NKPS, it was decided to raise the speed still further to 150 kilometers per hour. For such high speed the plant designed truck journal boxes with roller bearings and main and coupling rod ends on roller bearings on driving crankpin; the design was accordingly modified. As starting points in the design 400-440 RPM's of the driving wheels and 900 RPM's of the leading and trailing wheels were accepted.

In case of insufficiency of tractive force, the design called for a booster.

Because in 1936 the plant was busy building tenders with condensers, the building of fast 2-3-2 locomotives lasted until 1937. The first 2-3-2 locomotive was built for the twentieth anniversary of the Great October Socialist Revolution, and the second, by May 1938 (Figures 72 and 73).

Both 2-3-2 locomotives were delivered to the Oktyabr'skiy railroad. In April 1938 the first 2-3-2 locomotive during a test run developed the speed of 170 kilometers per hour. In the summer of the same year, after the second locomotive had been delivered in the road, tests for tractive force and road operation were begun on the Spirovo-Kalinin division. Tractive force tests were conducted with the first locomotive, and tests for road operation with the second.

For tractive force tests a special train with cars on roller bearings was prepared. In June - July runs with average speeds of over 100 kilometers per hour were begun with Professor A.M. Babichkov in charge of the tests. The Kolomna Plant was represented by the authors of the design headed by L.S. Lebedyanskiy.

A curve with switches near the station Shlyuz served as an obstacle to raising speeds to 150 kilometers per hour, because the Road Service put a limit of 100 kilometers per hour for this stretch of road. After considerable arguing this limitation was taken off. After this the average speed of 150 kilometers per hour and the maximum speed of 170 kilometers per hour were reached. While passing the station Shlyuz at a speed of 150 kilometers per hour, a cetain degree of leaning of cars was observed.

With such high speed, achieved in the USSR for the first time, the 2-3-2 exhibited exceptionally high operational qualities. With full throttle and 0.4 admission, specific steam consumption per crank horsepower per hour stayed within the limits of 6-7 kilograms. Such economy of operation was achieved for the first time. Thus, simultaneously two records were set.

On 31 August 1938 a locomotive with three cars, one of which was dynamometric, covered the Spirovo-Kalinin stretch at an almost continuous speed of 160 kilometers per hour. Throttle opening and admission were at the maximum. The speed of 150 kilometers per hour, set by the design as a limit, was reached quite satisfactorily both in the dynamics of the locomotive and in road observations.

Superheating reahed a temperature of 460 degrees which presented certain difficulties in lubrication. Cases of valve rods

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turning blue were observed and there was one case of burning of grease under the cylinder case. There were also cases of failure of superheater pipes.

Runs with speeds of under 100 kilometers per hour were made on the Butovskiy test ring.

In designing this fast locomotive the plant had to approach the solution of many problems in an altogether different manner from that in the design of locomotives of regular speeds. For instance, the starting point in calculations pertaining to driving gear was not the force of steam, but forces of inertia. The use of forged and pressed parts and of high quality steel reduced the weight of driving gear by 100-120 kilograms. In the process of building locomotives, cast leading wheels had to be balanced to eradicate the defects in casting. This balancing was done by drilling holes at certain points of the castings. This was the application of experience obtained in balancing the turbines used in tender steam condensers.

In service on the Oktyabr'skiy railroad 2-3-2 locomotives won high reputation. In the period from 1938 to 1940 they covered 170,000 kilometers.

An express train, "Red Arrow", being pulled by a regular Su locomotive on the run from Leningrad to Bologoye was 2 hours late. In Bologoye the S^u locomotive was replaced by a 2-3-2 locomotive which, on the run from Bologoye to Moscow, made up for the loss of 2 hours and arrived in Moscow on time, having covered the distance of 330 kilometers in 3 hours at a speed of 140 kilometers per hour.

It should be added that this was the second case of lost time

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having been made up thus. In 1933 an IS locomotive made up for the lost time in the same manner, having covered several stretches of road at a speed of 140 kilometers per hour.

Building of fast trains, so brilliantly started in the USSR, was interrupted by the war. Nothing came of the planned order for 10 more of these locomotives for the Oktyabr'skiy Railroad. This order will be postponed until the time when the roadbed, badly damaged during the war, will be fully restored to its original condition.

In 1946 both locomotives came back from the Eastern part of the country where they were evacuated during the war. They were put in order by the plant. To eliminate the difficulties in lubrication and to reduce superheating the plant replaced flues containing four superheater pipes with flues containing two superheater pipes. Superheating temperatures were lowered to 420 degrees. The second locomotive had originally a superheater with small flues. Brake pumps and stokers were replaced with new ones. The streamlined shell and brakes on the front and rear trucks were taken off, as well as the booster from the first locomotive (it was not installed on the second one).

All these features turned out to be superfluous at the time because, due to the condition of the roadbed, locomotives had to operate at speeds of 70 kilometers per hour.

In weighing the locomotive in this lightened condition the loads upon the wheel pairs were determined to be as follows: leading truck pairs, 12 tons per pair; driving, 19 tons; and trailing, 17 tons per pair.

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In a recheck of calculations of brake performance, brake coefficients (originally established on the basis of 160 kilometers per hour, at 80 percent for trucks and 70 percent for driving pairs, with a mean coefficient of 65.5 percent for locomotive and tender) because of temporary impossibility to achieve such a speed, became unduly high. Brake cylinders were originally equipped with safety valves. All this served as a reason for dismounting truck brakes. The problem of brakes for fast locomotives so far has to be considered as unsolved, but in time, when high speeds again will be possible, this problem will be permanently solved.

As to the operation of completely new parts of the locomotive, that is of roller bearings, it must be stated that it was quite satisfactory. Same results were obtained from needle bearings in swivel joints of steam distribution gear.

This successful experience was later utilized in building new 1-5-0 L locomotives.

The 2-3-2 locomotive as a type should be given much consideration also for speeds up to 120-130 kilometers per hour, with a wheel diameter of 1850 millimeters. With the load of 20 tons per wheel pair it could be widely used on our railroads, replacing the S^u locomotive.

A second type of fast 2-3-2 locomotive was built in 1938 by the Voroshilovgrad Plant. Only one experimental locomotive was produced (Figure 74). This locomotive was designed for even higher speeds than in the case of the Kolomna locomotives, namely, for 180 kilometers per hour. In this locomotive the Voroshilovgrad Plant used the boiler and the engine of the IS locomotive. The wheels are

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2200 millimeters in diameter. This locomotive is somewhat more powerful than the Kolomna 2-3-2. It is in service on the Moscow division of the Oktyabr'skiy Railroad where it operates under the same conditions as the Kolomna 2-3-2 locomotives. Its fuel consumption is higher than that of the Kolomna locomotives, but this is not conclusive because of present neigher types of 2-3-2 locomotives utilizes its potentialities to the full. To which of these two types the future belongs, right now it is impossible to say, because the Voroshilovgrad locomotive is still pretty much unknown, while the Kolomna locomotive has already exhibited exceptionally good qualities, as a result of which it can so far be considered the best Soviet passenger locomotive.

Characteristics of 2-3-2 locomotives are given in Table 32.

See Table 32 on following page.

29. TEST CHARACTERISTICS OF PASSENGER STEAM LOCOMOTIVES

In order to present a comparative evaluation of the passenger locomotives which were discussed in this chapter and which were subjected to a series of tests, figures taken from the summary of these tests should be given. For this purpose Table 33 is given below.

See Table 33 on following page.

This table gives values of maximum crank power $N_{k(max)}$ under definite conditions of operation (standard steam admission zm and speeds v, corresponding to $N_{k(max)}$. For many locomotives their general efficiency, obtained at the same speeds, is given. How-

TABLE 32

CHARACTERISTICS OF 2-3-2 LOCOMOTIVES

Series	Cylinder Diameter in Millimeters	Stroke in Millimeters	Driver Diameter in Millimeters	Pressure in Atmospheres	Heating Surface in Square Meters		Grate Area in Square Meters	Weight in Tons	
					Evaporating	Superheating		on Drivers	in working order
K num 1	580	700	2000	15	240	125	6.5	61.5	125
K num 2	580	700	2000	15	278	148	6.5	61.5	125
V	670	770	2200	15	248	119	7.04	64.5	138

LIST OF CAPTIONS FOR FIGURES FOR CHAPTER III

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IV

TANK LOCOMOTIVES

30. SWITCHING TANK LOCOMOTIVES

Tank locomotives on the wide-gauge railroad network of the USSR represent a type that is dying out. In the past there was use for these locomotives in switching and in suburban passenger service. Now, however, the building of special switching locomotives is not considered warranted since the switching service has a considerable reserve of locomotives that have been removed from passenger service because of their obsolescence. Switching operations are now performed mostly by O^V and E locomotives.

In industrial transport the tank locomotive is the basic type. However, discussion of locomotives for this type of transport was not in the author's plans, for which reason the author refers readers interested in such locomotives to Ye. I. Mokrshitskiy's book "A History of the USSR Locomotive building", 1941 edition.

These locomotives are called tank locomotives [In Russian beztendernyye, meaning "without a tender"] since they do not have separate tenders but contain water tanks and a supply of fuel within themselves.

The convenient feature of tank locomotives is the ease with which they can be handled in operations involving frequent changes in the direction of movement.

Among their shortcomings is the dependence of weight on drivers, and consequently the dependence of the traction power, upon the degree of exhaustion of the water tanks and the fuel supply which leads to a reduction in the weight of locomotive.

In addition, tank locomotives cannot stay away from the sources of supply of water and fuel, as a locomotive with a tender can.

The switching tank locomotives which operated on our railroads for 50 years are of many various types. They were mostly of 0-3-0 and 0-4-0 types (Figure 75). All switching locomotives were identified with a letter Ь [soft sign, usually transliterated as '].

The characteristics of switching tank locomotives are given in Table 34.

[See next page for Table 34]

31. TANK LOCOMOTIVES FOR TRAIN SERVICE

Tank locomotives found use as train service locomotives only in suburban traffic. Having insignificant reserves of water and fuel in comparison with locomotives with tenders, such locomotives cannot be used on lines with long runs.

At the present time almost all train tank locomotives have been already taken out of service, and new types are not being built, first, because old locomotives that used to pull main-line trains, are being used, and second, because of the steady electrification of suburban lines (the number of suburban steam locomotives generally is decreasing).

In suburban traffic tank locomotives used to operate on the Mineralovodsk line of the Vladikavkaz Railroad and between St.

THE MOST IMPORTANT CHARACTERISTICS OF THE 0-4-0 SWITCHING LOCOMOTIVE

Type and series	Cylinder diameter in mm	Stroke in mm	Driving wheel diameter in mm	Pressure in atmospheres	Heating surface in square meters	Grate area in square meters	Weight in tons	
							On drivers	In working order
0-3-0 Nevskiy plant	457	610	1150	12	103.6	1.6	54	
0-4-0 Nikolayevskiy RR	500	650	1200	10	123	1.85	52	

Petersburg and Pavlsovsk on the Moscow-Vindava-Rybinsk Railroad. On the first railroad there were for a time tank locomotives of the 1-3-1 type with a compound engine, some of which were built by the Rostov main railroad shops in 1896, and some built abroad (Figure 76).

They were modified to single-expansion engine and superheating and remained in service until the electrification of the Mineralovodsk line in 1936.

On the Moscow-Vindava-Rybinsk line tank locomotives of two types were operated: the 1-2-1, built abroad in 1900-1902, and the 2-3-0 of the Putilovskiy Plant, built in 1903-1904 (Figure 77). All these locomotives had a single-expansion engine operating on saturated steam.

In 1910 a 1-4-1 type tank locomotive was designed and built by the Nevskiy Plant for the Moscow Ring Railroad. This locomotive had a single expansion engine and no superheat (Figure 78).

In 1908 the Khar'kov Plant designed and built 2-3-1 tank locomotive for suburban trains of the Ryazan Ural Railroad. Eight such locomotives were built, six with superheat and two without superheat (Figure 79).

These locomotives had four-cylinder compound engines with a crankshaft.

The design called for a locomotive weight of 75.25 tons. However, when the completed locomotive was put on the scales, it weighed 106.1 tons, that is, it was 32 tons heavier than it was supposed to

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be according to the design. Because of the error made by the plant in calculating the weight, the plant was assessed damages amounting to the cost of separate tenders, which it had to build at its own expense.

Fuel oil tanks were kept on the locomotive. The tender was equipped with a device permitting its attachment at either the front or the rear of the locomotive. The result was a very clumsy locomotive, called a semitank locomotive. When the water tanks were taken off, the weight was reduced to 90.375 tons. Permission to operate this locomotives on suburban lines of the railroad was not received until 1910.

After a short period they were taken out of service.

The Garratt 2-4-1 + 1-4-2 locomotive built in 1932 in England on an order placed by the USSR for freight service is also a tank locomotive, since it does not have a separate tender. In its design this locomotive is not suitable for our operating conditions and it is unacceptable to us as a train service locomotive because of its complex construction.

The characteristics of train service tank locomotives are given in Table 35.

The traction and operational characteristics of most of the tank locomotives remain undetermined, because no scientific tests were conducted with them.

Individual tests, conducted by the railroads themselves, with few exceptions were not published in the press, and therefore, they are not presented here.

TABLE 35

CHARACTERISTICS OF TRAIN SERVICE TANK LOCOMOTIVES

Type	Cylinder diameter in mm: High pressure	Cylinder diameter in mm: Low pressure	Stroke in mm	Driving wheel diameter in mm	Pressure in atmospheres	Heating surface in square meters: Evaporating	Heating surface in square meters: Superheating	Grate area in sq. meters	Weight in tons: On drivers	Weight in tons: In working order
1-3-1	490	-	650	1550	11	133	-	1.5	52	70
2-3-0	480	-	600	1540	12	136	-	2.3	45	66
Moscow-Vindava-Rybinsk RR										
1-4-1	510	-	650	1300	12.5	171	-	2.8	62	86
Moscow Ring RR										
2-3-1 Ryazan Ural RR	2x380	2x590	600	1700	14	134	32	2.6	49	90.1

LIST OF CAPTIONS FOR FIGURES FOR CHAPTER IV

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